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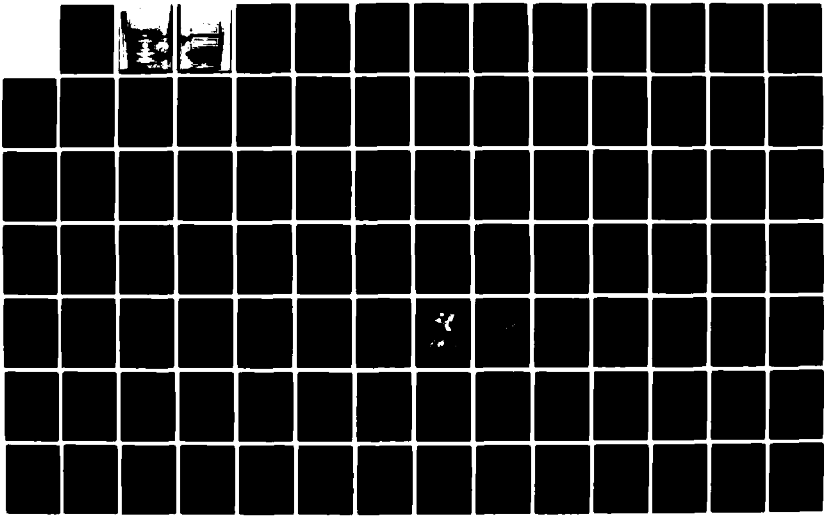

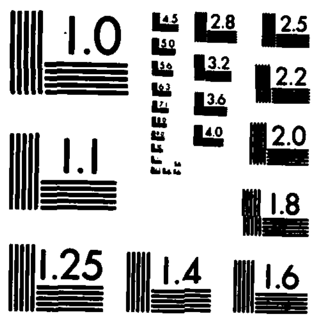
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Technical Report Documentation Page

1. Report No. FAA-EM-81-17,V	2. Government Accession No. AD-A123829	3. Recipient's Catalog No.
4. Title and Subtitle OCEANIC AREA SYSTEM IMPROVEMENT STUDY (OASIS) VOLUME V: NORTH ATLANTIC, CENTRAL EAST PACIFIC, AND CARIBBEAN REGIONS COMMUNICATION SYSTEMS DESCRIPTION		5. Report Date September 1981 6. Performing Organization Code SRI Project 8066
7. Author(s) B. Conrad		8. Performing Organization Report No. OASIS- COM-
9. Performing Organization Name and Address SRI International 333 Ravenswood Ave Menlo Park, CA 94025		10. Work Unit No. (TRAIS) 11. Contract or Grant No. DOT-FA79WA-4265
12. Sponsoring Agency Name and Address Department of Transportation Federal Aviation Administration Office of Systems Engineering Management Washington, D.C. 20591		13. Type of Report and Period Covered Final Report 14. Sponsoring Agency Code FAA-AEM

15. Supplementary Notes

16. Abstract

The Oceanic (and selected Non-Oceanic) Area System Improvement Study (OASIS), conducted by SRI International under contract with the Federal Aviation Administration (FAA), was part of a broad oceanic aeronautical system improvement study program coordinated by the "Committee to Review the Application of Satellite and Other Techniques to Civil Aviation" (also called the Aviation Review Committee or the ARC). The OASIS Project, with inputs from the international aviation community, examined current and potential future oceanic air traffic control (ATC) systems in the North Atlantic (NAT), Central East Pacific (CEP), and Caribbean (CAR) regions. This phase of the Aviation Review Committee program began in late-1978 and was completed in mid-1981.

The thrust of the Aviation Review Committee program, which OASIS broadly supported, was to analyze the present ATC systems; examine future system requirements; identify areas where the present systems might be improved; and develop and analyze potential system improvement options. The time frame of this study is the period 1979 to 2005.

This report describes the communication systems in use in the NAT, CEP an CAR.

17. Key Words Communication (COM), Oceanic Air Traffic Systems	18. Distribution Statement Document is available to the U.S. public through the National Technical Information Service, Springfield, Virginia 22161

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	98	

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Oceanic Area System Improvement Study (OASIS)

Final Report

This report is one of a set of companion documents which includes the following volumes:

Volume I
Executive Summary and Improvement Alternatives Development and Analysis

Volume II
North Atlantic Region Air Traffic Services System Description

Volume III
Central East Pacific Region Air Traffic Services System Description

Volume IV
Caribbean Region Air Traffic Services System Description

Volume V
North Atlantic, Central East Pacific, and Caribbean Regions Communication Systems Description

Volume VI
North Atlantic, Central East Pacific, and Caribbean Regions Navigation Systems Description

Volume VII
North Atlantic Region Flight Cost Model Results

Volume VIII
Central East Pacific Region Flight Cost Model Results

Volume IX
Flight Cost Model Description

Volume X
North Atlantic, Central East Pacific, and Caribbean Regions Aviation Traffic Forecasts

PREFACE

The Oceanic Area System Improvement Study (OASIS) was conducted in coordination with the "Committee to Review the Application of Satellite and Other Techniques to Civil Aviation (also called the Aviation Review Committee or the ARC)." This study examined the operational, technological, and economic aspects of the current and proposed future oceanic air traffic systems in the North Atlantic (NAT), Caribbean (CAR), and Central East Pacific (CEP) regions and assessed the relative merits of alternative improvement options. A key requirement of this study was to develop a detailed description of the present air traffic system. In support of this requirement, and in cooperation with working groups of the Committee, questionnaires were distributed to the providers and users of the oceanic air traffic systems. Responses to these questionnaires, special reports prepared by system provider organizations, other publications, and field observations made by the OASIS staff were the basis for the systems descriptions presented in this report. The descriptions also were based on information obtained during Working Group A and B meetings and workshops sponsored by Working Group A. The information given in this report documents the state of the oceanic air traffic system in mid 1979.

In the course of the work valuable contributions, advice, data, and opinions were received from a number of sources both in the United States and outside it. Valuable information and guidance were received and utilized from the International Civil Aviaiton Organization (ICAO), the North Atlantic Systems Planning Group (NAT/SPG), the North Atlantic Traffic Forecast Group (NAT/TFG), several administrations, the International Air Transport Association (IATA), the airlines, the International Federation of Airline Pilots Association (IFALPA), other aviation associated organizations, and especially from the "Committee to Review the Application of Satellite and Other Techniques to Civil Aviation."

It is understood of course, and should be noted, that participation in this work or contribution to it does not imply either endorsement or agreement to the findings by any contributors or policy agreement by any administration which graciously chose to contribute.

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EXECUTIVE SUMMARY

Oceanic communications required to support aviation in selected portions of the North Atlantic (NAT), Central East Pacific (CEP) and Caribbean (CAR) areas involve many elements including ground-to-ground communications between air traffic control (ATC) facilities and air-to-ground communications using very-high frequency (VHF) where available, communications are often conducted by special radio stations which relay messages to air traffic controllers.

The NAT is serviced by six major communications stations and the CEP by two. The CAR has a number of domestic service stations and control facilities providing VHF and HF communications to the majority of flights, and at least two major centers providing HF communications for long range over-water operations.

Ground-to-ground data such as flight plans are distributed among facilities via an international teletypewriter network called the Aeronautical Fixed Telecommunications Network (AFTN). Voice communication between controllers is accomplished over a network called the air traffic services (ATS) direct speech circuits. These two systems often use the same physical links.

Specifications for the communications system are recommended by the International Civil Aviation Organization (ICAO) and published by ICAO. Hardware and staff to man the communications systems are provided and paid for by the nations in which they lie.

Cost of the systems is born by governments in some states and by charges to users in other states. Air carriers bear the costs of installing and maintaining airborne radio equipment.

ACKNOWLEDGMENTS

We are highly appreciative of the guidance and support provided by the "Committee to Review the Application of Satellite and Other Techniques to Civil Aviation," particularly the support provided by Working Group B of the Committee and the Working Group's rapporteur, Mr. J. O. Clark. Special thanks are given to Mr. V. E. Foose, FAA Program Manager, for his assistance.

This research was conducted by SRI International under the leadership of Dr. George J. Couluris. This system description was developed by Dr. Bjorn Conrad with the assistance of Ms. Marika E. Garskis. Ms. Geri Childs prepared this report. The project was conducted under the administrative supervision of Dr. Robert S. Ratner and Mr. Joel R. Norman.

GLOSSARY OF ACRONYMS

AC	Aircraft
ACARS	ARINC Communications, Addressing and Reporting System
ADISP	Automated Data Interchange Systems Panel
AFTN	Aeronautical Fixed Telecommunications Network
AM	Amplitude Modulation
ANA/EP	Airports and Air Navigation Public Enterprise
ARINC	Aeronautical Radio Incorporated
ATC	Air traffic control
ATS	Air traffic services
CAR	Caribbean
CEP	Central East Pacific
CSSB	Compatible single sideband (A3H mode)
DSB	Double side band
ER	Extended range
ERVHF	Extended range very-high frequency
ESS	Electronic Switching System
FAA	Federal Aviation Administration
FIR	Flight information region
Hz	Hertz
HF	High frequency
IATA	International Air Transport Association
ICAO	International Civil Aviation Organization
IFR	Instrument flight rules
ITU	International Telecommunications Union
KHz	Kilohertz
km	Kilometer
kW	Kilowatt
LDOCF	Long distance operational control function
LDOC	Long distance operational control
m	Meter
mbar	Millibar
nmi	Nautical mile
MET	Meteorological
MHz	Megahertz
NAT	North Atlantic
NATSPG	North Atlantic Systems Planning Group
NDB	Nondirectional beacon
OTS	Organized Track System
s	Second
SAR	Search and rescue
SELCAL	Selective calling system
SENEAM	Servicies a la Navagacion en el Espacio Aero Mexicano
SSB	Single side band
USB	Upper side band
VFR	Visual flight rules
VHF	Very-high frequency
VOLMET	Aviation weather
W	Watt

1.0 COMMUNICATIONS SYSTEMS

Aircraft flying in oceanic areas must adhere to communications rules defined under the International Civil Aviation Organization (ICAO). ICAO publishes "international which contain these rules. The document entitled "International Standards, Rules of the Air, Annex 2 to the Convention on International Civil Aviation," commonly known as Annex 2 (ref. 1) is of particular concern here. Pertinent excerpts from Annex 2 are shown on page 2. In brief, they state that, unless exempted by air traffic services (ATS) authorities, user aircraft must have continuous two-way communications capability with (ATS) in controlled airspace, but no explicit requirements are placed on the methods used to maintain such communications. In uncontrolled airspace two-way communications may be required.

ICAO publishes "Regional Supplementary Procedures," Document 7030/2 (ref. 2). These procedures require two-way communications in the Caribbean (CAR) in all areas unless exempted by the air traffic control (ATC) authorities responsible for the flight informationregion occupied by the aircraft. A pertinent excerpt from Document 7030/2 is presented on page 3.

The requirement for two-way communications between aircraft and ATS personnel is filled in many ways. These ways often include relaying messages between various ATC centers communications stations which actually are in contact with aircraft. Hence, the aeronautical mobile communications system is, in part, dependent on the existence of ground-to-ground as well as air-to-ground links.

Oceanic aircraft operations are supported by a myriad of interconnected communications links. These links are operated or procured by States that provide services in Flight Information regions (FIR) as defined in ICAO regional planning documents (ref. 3,4). The links include aeronautical mobile communications elements in the form of very-high frequency (VHF) and high frequency (HF) radio between aircraft and ground, and an assortment of ground point-to-point elements with voice and data interchange capability. Ground communications utilize cable, radioteletype, and satellite channels.

Private networks also operate HF mobile services. For example, ARINC and various airlines use HF frequencies for long distance operational control (LDOC).

EXCERPTS FROM ANNEX 2 DEFINING COMMUNICATIONS REQUIREMENTS

3.6.3 Position Reports

Unless exempted by the appropriate ATS authority or by the appropriate air traffic services unit under conditions specified by that authority, a controlled flight shall report to the appropriate air traffic services unit, as soon as possible, the time and level of passing each designated compulsory reporting point or reporting line, together with any other required information. Position reports shall similarly be made in relation to additional points or reporting lines when requested by the appropriate air traffic services unit. In the absence of designated reporting points or reporting lines, position reports shall be made at intervals prescribed by the appropriate ATS authority or specified by the appropriate air traffic services unit.

Note: The conditions and circumstances in which SSR Mode C transmission of pressure altitude satisfies the requirement for level information in position reports are indicated in the PANS-RAC, Part II.

3.6.5 Communications

3.6.5.1 An aircraft operated as a controlled flight shall maintain continuous listening watch on the appropriate radio frequency of, and establish two-way communication as necessary with, the appropriate air traffic control unit, except as may be prescribed by the appropriate ATS authority in respect of aircraft forming part of aerodrome traffic at a controlled aerodrome.

Note: SELCAL or similar automatic signalling devices satisfy the requirement to maintain a listening watch.

5.3.2 Communications

When so prescribed by the appropriate ATS authority, an IFR flight operating within specified areas or along specified routes outside controlled airspace shall maintain a listening watch on the appropriate radio frequency and establish two-way communication, as necessary, with the air traffic services unit providing flight information service.
Note: See Notes following 3.3.1.1.2.1 c) and 3.5.5.1.

5.3.3 Position Reports

An IFR flight operating outside controlled airspace and required by the appropriate ATS authority to:

- submit a flight plan,

- maintain a listening watch on the appropriate radio frequency and establish two-way communication, as necessary, with the air traffic services unit providing flight information service,

shall report position as specified in 3.5.3 for controlled flights.

Note: Aircraft electing to use the air traffic advisory service whilst operating IFR within specified advisory airspace are expected to comply with the provisions of 3.5, except that the flight plan and changes thereto are not subjected to clearances and that two-way communication will be maintained with the unit providing the air traffic advisory service.

EXCERPTS FROM "REGIONAL SUPPLEMENTARY PROCEDURES"
Document 7030/2 of ICAO

5. AIR-GROUND COMMUNICATIONS AND IN-FLIGHT REPORTING

Note: Annex 2, 3.6.3, 3.6.5.1 and 5.3.3, and PANS-RAC, Part II, 13, require controlled flights and certain IFR flights outside controlled airspace to maintain a continuous listening watch on the appropriate radio frequency and to report positions in specified circumstances. The following expands such requirements and specifies additional details regarding the transmission and contents of in-flight reports.

5.1

Application
(A 2-3.6.3, 3.6.5, 5.3.3; P-RAC, Part II-13)

5.1.1

All aircraft on VFR flights, and aircraft on IFR flights outside controlled airspace, shall maintain a watch on a radio station furnishing communications for the unit providing flight information service in the flight information region and file with that station information as to their position unless otherwise authorized by the State overflown.

(Applicable to AFI, CAR, MID/SEA, PAC, SAM)

The remaining sections of this report describe these systems--first in their entirety, followed by a detailed view of each separate region. Section 2.0 contains an overview of the systems used to meet the requirements of ICAO Annex 2. Sections 3.0, 4.0, and 5.0 provide specific information on the North Atlantic (NAT), Central East Pacific (CEP), and Caribbean (CAR) communications, respectively.

2.0 COMMUNICATIONS SYSTEM OVERVIEW

2.1 Background

In the oceanic environment, aviation communications are often less reliable and slower than those typically available in highly developed airspace. Dense, domestic airspace is often controlled with extensive radar vectoring, much radar controller intervention (to prevent conflicts), and dynamic adjustments to aircraft flight plans both within and near boundaries of adjacent control centers, all of which require rapid reliable communications. The oceanic environment operates within more rigid limitations (e.g., aircraft very far apart, rigid routings in some areas); this results in an operational environment which is less dependent on communications for minimizing collision risk.

Examples of functions performed by existing communications systems are presented in the accompanying listing on Page 6. There is little technical data which can be used to weigh the relative importance of each function in numerical terms. The communications system, as we know it today, has its roots in the historical experience of the aviation community who have formed and adapted the system over time. During this project, however, all of the oceanic communications functions listed below were either observed directly or extracted from specific experiences related to project personnel by controllers, airline staff, etc.

Communications are provided to and from the following major points in the oceanic environment:

(1) Aircraft (primarily via HF and some VHF).

(2) Radio communications centers which operate HF and VHF radio transmitters and receivers and actually talk to aircraft.

(3) ATC facilities, which plan, coordinate, and monitor oceanic movements (and occasionally talk directly to aircraft).

(4) Domestic ATC facilities which tactically guide aircraft onto and off of oceanic tracks or routes.

(5) Clearance facilities which deliver oceanic clearances to A/C while in domestic airspace.

(6) Air-carrier facilities where route structures are posted and flight plans are filed.

(7) Meteorological centers which provide weather data for flight planning purposes.

Oceanic Communication Functions

- Controllers can, to a limited extent, monitor and effect aircraft adherence to flight clearances.

  Examples:

  - Occasionally aircraft speeds are altered to maintain longitudinal spacing based on aircraft radio reports to and from aircraft.

  - Occasionally errors in the flight plan are detected and corrected.

- Increase efficiency with which airspace is used

  Examples:

  - Adjacent centers can alter interface rules and routes. For example, tracks in the NAT are shifted via communications between Gander and Prestwick in response to changing meteorological conditions.

  - Aircraft may be allowed enroute altitude changes if communications allow ATC messages and verification of position of possibly conflicting aircraft.

  - Actual meteorological conditions can be fed back from aircraft for use in efficient route planning.

  - Raise and lower crossing traffic to effect efficient operations.

- Emergency services are enhanced

  Examples:

  - Enroute a/c failures can be handled expeditiously

  - Aircraft position reporting (or lack thereof) can expedite SAR when necessary.

  - Passenger/crew medical problems can be aided by discussions with ground facilities.

  - Aircraft mechanical failures may be evaluated by remote specialists.

- Expedite the use of personnel and equipment

  Examples:

  - Special aircraft maintenance or fuel needs can be planned via advance communications with company facilities.

  - Aircraft can be informed of conditions which might cause them to request alternate flight plan routings.

- Miscellaneous functions

  Examples:

  - Where oceanic airspace interfaces with small domestic regions, political or economic considerations can necessitate coordination with those domestic regions.

  - Permit aircraft flight dispatchers to track and issue special condition information to aircraft.

Unlike typical domestic controllers, oceanic controllers do not normally talk directly to aircraft. When out of domestic airspace, aeronautical mobile communications are instead directed to special ground communications stations. Such stations are often operated by a designated provider state within each ICAO defined FIR. In addition, private carriers or companies (such as the British Airway station called Speed-Bird-London) maintain radio facilities to provide company message capability when necessary or contracted for by provider states such as the contract arrangement between ARINC, Inc. and the Federal Aviation Administration (FAA).

Primary long range aircraft communications are via HF radio frequency band assignments obtained from the International Telecommunications Union (ITU) by request of ICAO and the carriers. The use of groupings of frequencies sometimes called "families" for a particular region is recommended by ICAO.

Most of the ground facilities listed above can communicate with each other via a system of communications links, such as:

(1) The Aeronautical Fixed Telecommunications Network (AFTN), a set of links recommended by ICAO and supported by ICAO and provider states which sends teletype messages between points with automatic or manual switching at various points to allow transmission of flight plans and other messages between most major aviation facilities.

(2) Direct speech circuits are much like (1) above. (These lines also provide some remote VHF transceiver siting.) Speech circuits are referred to as ATS circuits and are part of the ATS network.

(3) Miscellaneous lines used for weather and interconnection of facilities, such as telephone lines between radio communications stations and their associated ATC facilities.

The most important of these links are those connecting oceanic facilities. Various flight plan and carrier communications paths within domestic areas must be supported for domestic as well as oceanic purposes and hence are of secondary interest to this project.

Figure 1 shows the areas whose civil aeronautical mobile and fixed communications lines are of interest to this project. Military communications systems operate in parallel with the civilian systems. Military radio stations handle much of the military air-to-ground communications and transmit information to civilian control centers over the AFTN network or special lines as necessary.

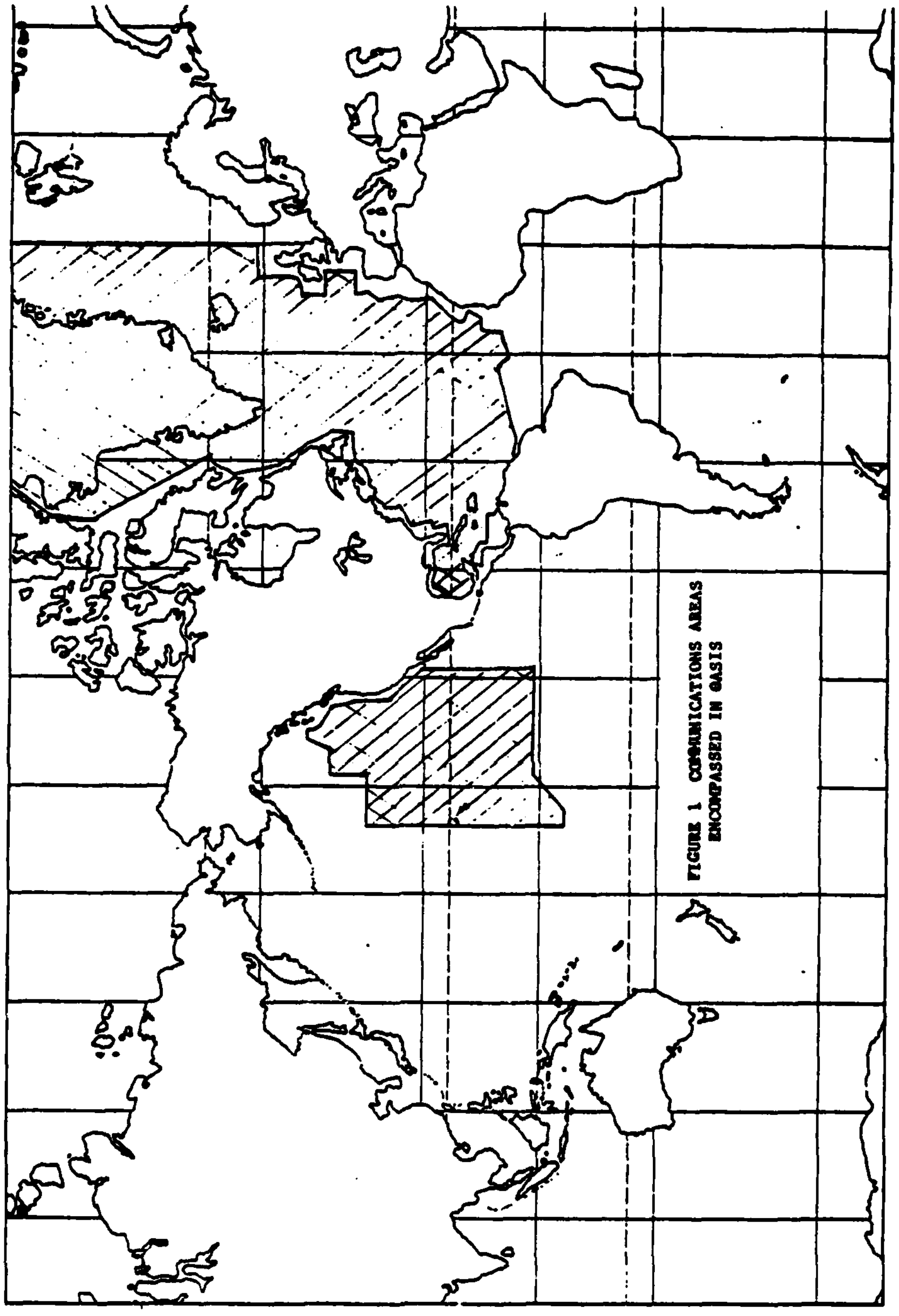


FIGURE 1 COMMUNICATIONS AREAS
ENCOMPASSED IN OASIS

The functions of the communications system vary slightly from region to region and reflect local system needs. The NAT, for example, with its relatively dense loading utilizes a shifting track system that imposes daily coordination requirements between centers defining the tracks, whereas the CEP has fixed tracks. Typical communication requirements involved in routine oceanic flights are shown in the accompanying listing on Page 10.

2.2 Physical Description of the Aeronautical Mobile System

Air-ground communications over the ocean involve the following elements:

(1) VHF and HF frequencies allocated for communication and technical specifications for using those frequencies (e.g., modulation characteristics).

(2) Suitably distributed ground stations with transmitters, receivers and antennas and such auxiliary facilities as selective calling devices (SELCAL).

(3) On-board aircraft transceivers and antennas and assorted auxiliary equipment such as selective signaling equipment (e.g., SELCAL).

In addition, procedures and staff are required to talk to aircraft and other facilities, and to key teletype messages into the AFTN, etc. Ground communication stations require links to other ground stations, often through connections to the AFTN.

2.2.1 VHF Communications

Although VHF is generally thought of as a short-range communications medium, VHF often provides coverage to high altitude aircraft within a 200 nmi radius of a transceiver site. VHF transmitter sites are often located at continental landfall or on islands to provide some oceanic coverage. In addition, extended range VHF (ERVHF) is often used to provide coverage to 400 nmi. This is accomplished by using directional antennas and high power.

VHF is particularly important in very northerly NAT routes (which happen to be in areas of poor HF coverage and handle many ferry flights), the Caribbean, and at entry and exit to oceanic routes where critical communications such as ATC clearance changes, equipment checks, etc., occur.

Because VHF is the primary communications mechanism for all terminal areas used by domestic and oceanic aircraft, all aircraft are equipped with high quality VHF radios. VHF is universally used for direct controller/pilot conversation wherever radar control is exercised

Typical Communications Involved In Routine Oceanic Flights

- Carrier receives messages defining routes; weather, etc. using AFTN or other services.

- Carrier (generally before takeoff) files an oceanic flight plan transmitted to appropriate ATC centers via a land data link.

- Later (often after takeoff), while within domestic airspace, an aircraft is issued a formal oceanic clearance (generally over a VHF radio).

- Domestic and oceanic centers communicate time and route (or track) which are assigned to a flight.

- When on oceanic routes, aircraft commences making position reports (approximately every 45 minutes) to radio facilities (via HF or VHF if within range) who forward reports to ATC facilities or other facilities as appropriate.

- Aircraft also transmit meteorological data, clearance change requests, etc. enroute as above.

- ATC sends clearance changes, or other data as necessary to radio facilities for transmission to aircraft.

- ATC sends information to adjacent FIRs prior to aircraft arriving at boundaries.

- Radio facilities issue weather forecasts periodically on designated frequencies.

- Oceanic centers transmit handoff data to adjacent centers prior to aircraft arrivals at boundaries.

and at all busy airports. Even in remote domestic continental areas, VHF may be used to talk to radio centers that provide information (such as weather) and/or relay messages to controllers.

The cost, convenience, quality and universality of VHF make this means of communication desirable for air-to-ground or air-to-air correspondence. The relatively short range (line of sight) of VHF constrains its use to places where convenient land sites are available for transceiver locations. Remote facilities must have adequate power to operate their transmitters and a voice quality (e.g., 3 KHz) line to communicate with the remote user. Occasionally, ground transceivers are located on land sites that are very remote from operators. Greenland, for example, has stations that are operated remotely by Gander radio operators. VHF ground transmitters generally have effective radiated powers of 100 to 1,000 W.

2.2.2 HF Communications

HF (2.850 to 30 MHz) is used extensively for mobile communications between marine, aviation and land vehicles, and other vehicles and ground points. HF also provides a low-cost, low speed communications medium for point-to-point data and voice transmission.

In actual practice, most aviation HF communications are carried out by dedicated communication stations rather than by ATC centers. There are several historical reasons for this (some of which may no longer be valid):

(1) Individual HF transceiver channels (frequencies) have time-varying geographical coverage characteristics so a user must alter channels occasionally to maintain communications.

(2) HF is inherently noisier than its shorter ranges counterpart--VHF.

The transition to modern solid state airborne and ground equipment, the change from double sideband (DSB) to single sideband (SSB) modulation and the formal distribution of frequencies, and the concept of networking may mitigate many historical problems associated with HF communications.

The ambient noise associated with monitoring an HF frequency led to the development of SELCAL, a set of devices which permits aircraft to be selectively called from the ground without monitoring audio. This system is an important part of HF communications.

2.2.2.1 HF Modulation Procedures and SELCAL

Historically, the HF frequency bands dedicated to aeromobile aviation have been used for conventional AM (amplitude modulation) wherein a voice signal is scaled and biased and then mixed (multiplied)

with a carrier frequency signal. This type of signal (called mode 'A3') is particularly easy to produce and demodulate, and the presence of a large carrier component is convenient for generating a frequency reference at the receiver.

Actually, for voice information, the carrier signal need not be sent (can be "suppressed")and only one side of the spectrum need be transmitted. This is single sideband (called A3J) communication requiring more sophisticated equipment. Approxmately 90 percent of NAT aircraft (ref. 5) are now equipped with SSB capability. Figure 2, copied from Arinc characteristic 719, (published November 16, 1978 by Aeronautical Radio Incorporated in Annapolis, Maryland) shows the allowed spectrums for AM and SSB signals.

Unfortunately, it is hard with pure single sideband (A3J) to discriminate between transmitted low frequency tones, used in some data transmission and signaling schemes, because no reference signal is available to detect the carrier, and signal frequencies do tend to drift and experience doppler shift. Potential problems with tone transmission are exemplified by SELCAL. This is a system used by radio operators to alert specific aircraft to turn on their audio output for a message. Each aircraft has a device which 'listens' for low frequency tones occurring in pairs. It is implemented (ref. 6) by sending out two low frequency tones over a voice channel for about 1 s, pausing and sending out two (possibly different) tones. The tones are chosen from the frequencies range 312.6 to 977.2 Hz and must be discriminated to within about 1 Hz by a receiver. To alleviate this problem a mode A3H containing carrier frequency signals is used.

A receiver can recover SELCAL tones accurately when A3H transmission is used. Hence, SELCAL requires carrying an A3H detection mode on airborne receivers with SELCAL and A3H transmitters at ground stations with SELCAL transmission capability.

It is currently planned that most aeronautical mobile HF communications, with the exception of SELCAL, will be A3J by the middle 1980s. Various associated entities such as ICAO committees and the North Atlantic System Planning Group (NATSPG) have reached agreement with providers of HF to provide SSB in the NAT, and ICAO regional plans (e.g., see ref. 4) called for SSB in other areas. In addition, the ICAO Communication Divisional Meeting in 1978 recommended that the requirement for SSB be incorporated into Annex 10 by the Council of ICAO. Hence, any changes recommended to the HF system should consider being compatible with this mode of operation and/or the cost of adding modes to existing equipment.

Detailed specifications for the transmission of signals are in Volume I of Annex 10 to the Convention on International Civil Aviation, "International Standards, Recommended Practices, and Procedures for Air Navigation Services, Aeronautical Telecommunications." In that document

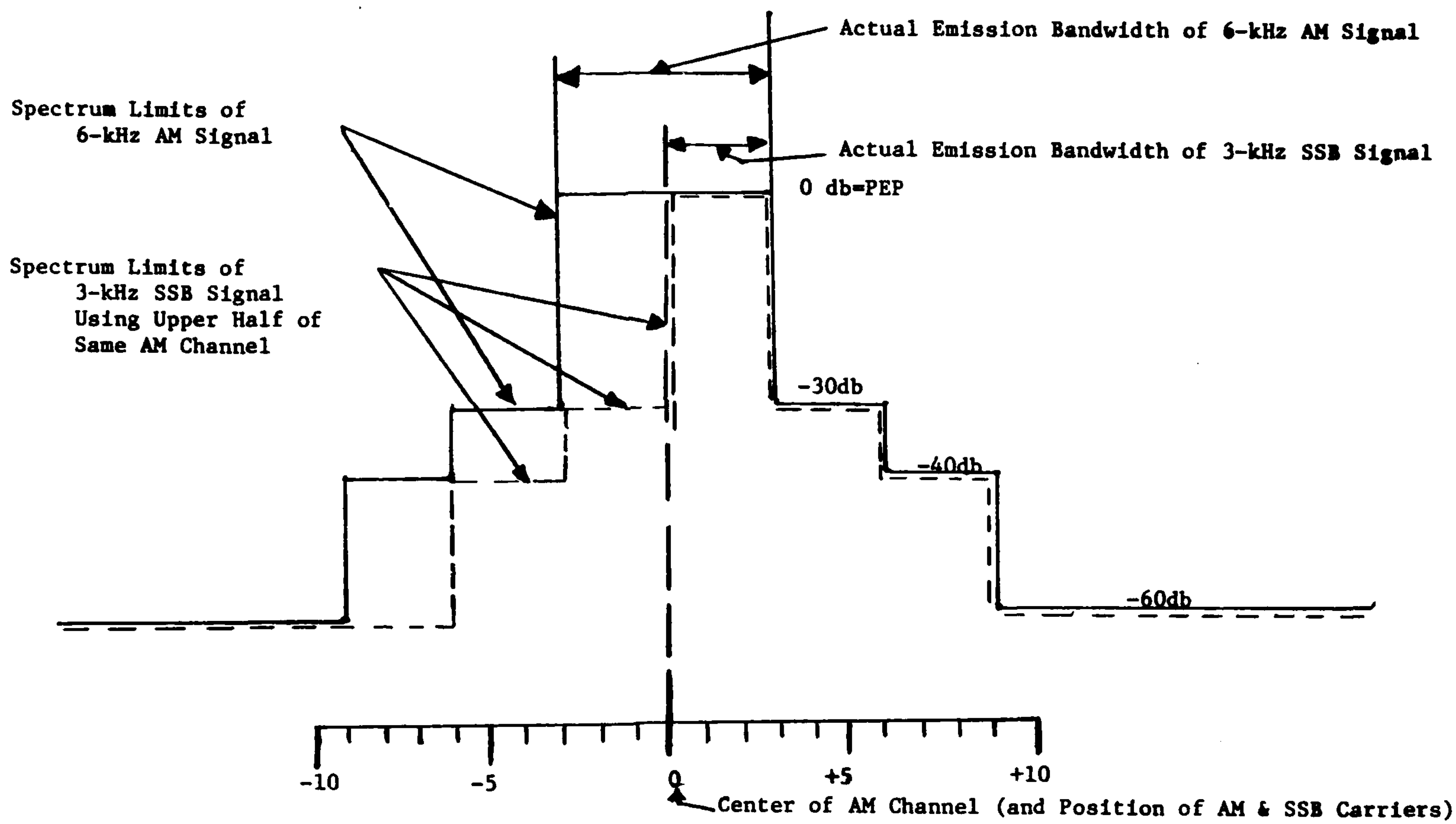


Fig. 2 Comparison of Spectrum Characteristics of AM & SSB Signals Operating on Same Assigned Carrier Frequency Based on Specification Requirements of ARNIC Char.

such factors as signal power and spectrum shape limitations are defined. Appendix A presents some reproduced material from Annex 10. Appendix B presents material which appears in the updated, 1978 Appendix 27 of the ITU (ref. 7). A new appendix was generated in 1979 and contains some realocation of HF frequencies.

2.2.2.2 HF Propagation Characteristics

Each ground station that must communicate over long distances (e.g., over the horizon) uses the ionosphere to propagate its signals and must have available a range of frequencies in order to maintain communications. Hence, frequencies have been allocated to areas or facilities in "groups" or "families." Within each of these families, each of which generally consists of 4 or 5 frequencies spanning the 2 to 13 MHz range, two frequencies can generally be found which will propagate at any given time of the day. Major radio stations such as Shannon have four families of frequencies in operation. Appendix C contains a description of the physical phenomenon affecting propagation.

2.2.2.3 Frequency Assignments

In practice, several aeronautical stations share common frequency assignments and thus intercept one another's traffic. Because HF long-range propagation contains so many vagaries, this "networking" is utilized to provide communication redundancy There is often a significant likelihood that a frequency might propagate between an aircraft and a station when it is not propagating to another (possibly closer) station. By tying together all ground stations with a ground communications network, messages can be relayed around the network.

Procedures for designating frequencies for particular aircraft flights vary considerably from region to region. In well developed areas, such as the NAT and CEP there are some established rules for choosing frequencies. For example, in the NAT tracks, frequencies are chosen from families according to the scheme shown below:

NORTHERN TRACKS

All DSB equipment use family D
All SSB A/C registered west of 30 degrees West use B
All SSB A/C registered east of 30 degrees West use C

CENTRAL TRACKS

Same as northern tracks

SOUTHERN TRACKS

All aircraft use family 'A'

Aircraft are designated frequencies (a primary and secondary) based on the time of day. Published charts and manuals carried by aircraft also contain all monitored frequencies which aircraft may try to contact

Table 1

HF FREQUENCIES

FREQUENCY	(KHz)	COMMENTS
2931 5610 8945 13328	NAT-A Family	Used primarily for all Southern NAT traffic tracks by Gander, Shannon, NY, Santa Maria, San Juan, Lisbon, Paramaribo
2987 5673 8889 13288 17941	NAT-B Family	Used primarily for central and northern NAT tracks--SSB A/C registered W of 30 degrees W by Gander, Shannon, NY, Santa Maria, Reykjavik
2945 5638 8854 13288	NAT-C	Used primarily for central and northern VHF tracks--SSB A/C registered E of 30 degrees W by Gander, Shannon, Santa Maria, Reykjavik
2868 5624 8910 13328 17941	NAT-D	Used primarily for DSB (older) aircraft flying northern and central NAT tracks by Gander, Shannon, Reykjavik (also Norway and Missel, Canadian points)
3001 3467 5554 5603 8875 8931 13312 13336 17909	CEP 5	Used for CEP traffic, much of which is between Hawaii and West Coast of U.S. by Honolulu and San Francisco ARINC facilities, operate as CEP-5-N and CEP-5-S

* Some additional allocations were also available. (3467, 5554, 6568, 8931, and 11303).

**In February 1983 these frequency assignments will be changed.

Table 1 (concluded)

2952		Used by NY, San Juan, Santa Domingo
5484		for Caribbean traffic
6540	E-CAR	
8959		
11343		
13320		
2966		Used by Merida and New York for
5568		Caribbean communications
8840		
10017	W-CAR	
11343		
13320		
17925		
2980		Oakland-Honolulu-Anchorage
5519		Volmet-(A3H) by FAA broadcast only
8903		
13344		
3001		
5652		NY-Gander
8868		Volmet-(A3H)
13272		

if their primary and alternate prove unsatisfactory. In addition to this, aircraft relay (via VHF or HF) messages via other A/C when no frequency appears to propagate.

2.2.2.4 Current Status of Aeronautical Mobile Frequency Utilization and Reliability

There are two major aspects of HF frequencies which are difficult to judge:

(1) The efficiency of worldwide use of aeronautical frequencies.

(2) The "dependability" of HF links.

Only in the NAT has very detailed analysis of frequency loading been carried out. That analysis has involved message delay analysis, individual channel loading, etc., on a yearly sample basis. No hard data is available on such dependability factors as rarely occurring signal fades, which may last for periods ranging from seconds to hours and can wipe out some or all of the aeronautical mobile frequencies in a given area.

HF communication centers have not been consistently recording data describing communication failures. Furthermore, with the advent of new equipment for ground and airborne installations that have switched to SSB, there appears to be better reliability in communication links than hitherto has been experienced. There are various computer models available for analyzing and predicting HF propagation characteristics. The utility of these for predicting severe and isolated cases of communication failure, however, may be limited, because such cases occur rarely and hence are difficult to model.

Table 1 contains groupings (families) of HF frequencies currently available in the NAT, CEP, and CAR regions. More than one station typically has the facilities to use all or part of a family. Antenna directionality and other factors, however, influence who can use which frequencies where. As of 1978, the ITU World Administrative Conference proposed a replacement of the existing 14 NAT frequencies in four families by 23 frequencies in six families as shown in Table 2.

Figure 3 shows a map of coverage extracted from the regional plans (ref. 3, 4). This figure is not indicative of where the HF frequencies can be used based on either flight checks or calculations, but only an indication of the areas that were planned to be covered.

Appendix 27 of the ITU considers four classes of aeronautical mobile communications:

Table 2

HF FREQUENCIES: EXISTING AND PROPOSED FREQUENCIES
IN USE FOR AERONAUTICAL MOBILE COMMUNICATIONS

Existing Frequencies

A	2931	5610	8945	13328
B	2987	5673	8889	13288
C	2945	5638	8854	13288
D	2868	5624	8910	13328

Proposed Frequencies

2872	5598	8825	11279	13291
2899	5516	8864	11309	13306
2971	6622	8879	11336	13306
3016	5649	8891	11279	13291
2962	6628	8906	11309	13306
3476	4675	8831	11336	13291

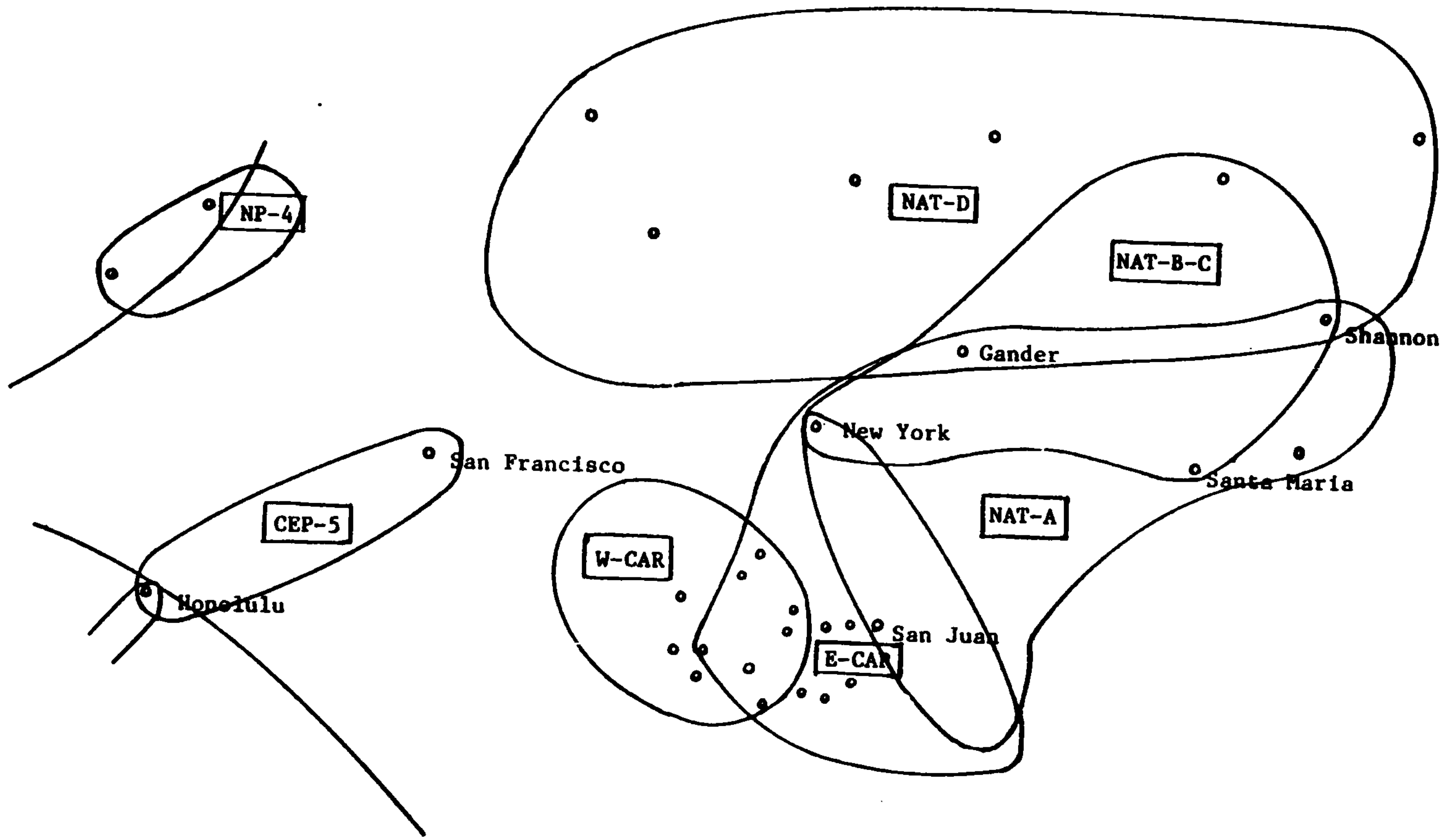


FIGURE 3 HF FREQUENCY ASSIGNMENT BY AREA

(1) Major world air route areas.

(2) Volmet, which is weather aviation information that is continuously broadcast on specified frequencies

(3) Regional and domestic air routes.

(4) Aeronautical operational control.

Appendix 27 of the ITU also contains worldwide definitions of (overlapping) areas and tables which allot groups of channels by area, class of use and (sometimes) time of day.

The NAT frequencies are sampled each year for the purpose of analyzing the status of the communications system. In 1972 a very detailed analysis was conducted in order to determine channel occupancy times and other parameters (ref. 8). Subsequent (yearly) efforts involve primarily the collection and analysis of position report occurrences by frequency, ground station, and period of the day for VHF as well as HF channels. Position report delay parameters are also estimated. Because a 1972 report showed that position reporting dominates HF channel utilization, yearly collections of statistics for only this type of report have been deemed adequate for estimating the state of the system.

A 1 day summary of data from July 28, 1978 (ref. 5) is shown in Table 3. This kind of data is collected yearly. Note that position reports have been counted by time slot, frequency and station. ARINC, in an analysis of messages for a satellite study (ref 9.), also did message analysis using taped data. Table 4 shows the fairly detailed message-type breakdown that ARINC obtained; results also showed position reports to dominate HF communications channel time.

2.2.3 Aeronautical Mobile Ground Stations

Table 5 contains a list of major ground facilities (relevant to this study) providing HF or VHF radio coverage to aircraft. Some CAR stations are not listed. All of the facilities that receive transmissions from aircraft serve as message relay centers between aircraft and various control centers and/or other ground points such as weather services or airline dispatching offices. The principal difference between various NAT, CEP, and CAR ground centers is one of scale. Figure 4 is a schematic of a typical HF mobile communications facility. Transmitters generally produce output power in the 2 to 5 kW range.

HF sites require a significant bit of real estate. Good HF antennas generally must have dimensions on the order of a wavelength. In the 3 MHz band this is about 100 m. In the 17 MHz band this drops to 17 m. With respect to Figure 4, this generally means having remote antenna sites connected by remote communication links such as microwave or telephone cable.

Table 3

RESULTS OF 1-DAY SAMPLING OF POSITION REPORTS

DISTRIBUTION OF POSITION REPORTS BY STATION AND FREQUENCY

STATION	SAN JUAN	NEW YORK	SANTA MARIA	GANDER	SHANNON	REYKJAVIK	SONDRE STROMFJORD	TOTALS
FREQUENCY	TP VS YI	QL TP VS YI TY VK YD	CT TY VK TT VF QL TP VS YD YI	QT TY VK QN TT VF QC TR YN TP VS YI YD	QL TP VS QN TT VF QT TY VK QC TR VN	TY VK QN TT VF TS VN [illegible]	TS VN [illegible]	
HOUR 0000-0059	1	6 1 1	1 2 4 3	3 1 4 2 1 1 2	2 1 2 4 2	1 6		56
0100	1 1	1 7 2 1	1 1 1 1 7 5	8 3 10 1 8	1 3 3 3 3 1	6		73
0200	4 1 1	2 5 5 4	3 9 8 10 1	4 6 6 21 1 1 2	3 2 1 11 6 5	2 1 6 2		132
0300	3 2 2	1 5 6 2	8 2 9 8 13	8 9 10 22 4 6 2	8 14 6 6 8 4	4 1		166
0400	9	2 10 4 1	2 1 5 15 9	2 20 11 19 8 3 1	1 2 18 3 5 7 6 4	1		165
0500	6	2 10 3 1	1 2 10 9	9 11 10 11 3 6 2	1 15 12 5 19 1 8 1	1		154
0600	9	18 1	1 1 7 16	3 5 1 16 15 5 3	4 1 2 22 2 21 5 3	1 1 2		159
0700	7	13 1	3 16	2 5 2 10 4 1 4	2 3 2 17 1 1 8 1 11 2	1 3		118
0800	1 5	1 2 6	1 1 2 13	4 2 4 2	2 2 11 1 11 4 3 1	1		77
0900		2 1	1 6 10 1	6 3	4 10 9 2	1 2 1		57
1000			1 17	3 4 1 1	1 3 3 1 4 1	2 1 2		45
1100			2 3 13 1	1 4 3 1	1 5 6 8 3 3 1 1	6 5 3		70
1200		1 1	1 13 1	2 2 4 6	4 7 8 8 8 3	1 10 4 1		54
1300		2 2 1	2 13	1 9 3 12 1 1	3 6 14 16 6 4 6	2 3 6 6		117
1400	1 2	2 5 2	16 6	8 13 5 7 6 1 2	5 13 13 10 7 2 4	4 4 10	1	153
1500	2 1	6 4 1	16 2	2 14 2 11 1 6 1 1 1 4	2 12 12 8 10 6 3	1 6 5 10	1 2 1	160
1600	3	2 6 1 4	17 2	3 7 3 19 1 7 1 3	1 1 11 8 6 6 4 3	3 3 10	1 1	141
1700	1 2	4 7 2 1	11 5	1 14 5 15 5 3 1	1 2 11 6 7 7 5	10 4 1	1	13[illegible]
1800	1 2	6 6	1 10 3	9 4 10 1 4	7 2 16 4 2 6 3 4	1 1 4 3	1	112
1900	1 3	2 8 1	1 4 1	1 5 1 14 3 1	3 3 7 10 3 5 1 1	1 2 2 1		85
2000	1 2	2 4 1	5 6	6 17 3 1	2 6 6 3 3 1 2	1		71
2100	1	5 1 1	3 6	2 8 12 3	3 2 3 1			4[illegible]
2200	3	2 1	5 4	2 1 1 4	3 1 1 1 2	1		[illegible]
2300	1 6	5 3 1	3 3	1 1 2 1 1	6 1 1 3	[illegible]		[illegible]
TOTAL	11 56 19	4 12 47 45 26 22 7	1 16 10 1 1 38 93 31[illegible] 35	39 92 97 53 151 137 14 30 41 30 10 2 10	5 42 43 78 117 97 19 [illegible] 61 18 [illegible] 37	5 4 1 1 42 54 78 [illegible]	[illegible] 4 1	2 4 [illegible]
TOTAL VOLUME REPORTS	NIL	NIL	50	454	132	230	67	[illegible]

Source: Excerpted from Ref. 5.

Table 4

EXAMPLE OF MESSAGE TYPING SCHEME

ARINC MESSAGE TAPE DATA (Taken from records for 18 April 1974)

Message Type	High-Frequency Transmission															Very High Frequency Transmission									Total Number of Occurrences		
	New York Family A 0000-0600Z		New York Family 1500-1800Z		New York Family B 0000-0300Z		New York Family B 1400-1900Z		San Juan E CAR 0300-0600Z		San Juan E CAR 1500-1800Z		Subtotal HF			New York VHF 0000-0600Z		New York VHF 1500-1800Z		Miami VHF 1500-1800Z		Subtotal VHF					
	NO	RB	NO	RB	NO	RB	NO	RB	NO	RB	NO	RB	NO	RB	Ratio of NO to Number of Messages (%)	NO	RB	NO	RB	NO	RB	NO	RB	Ratio of NO to Number of Messages (%)	NO	RB	Ratio of NO to Number of Messages (%)
1. Air Traffic Control Instructions																											
1.1 Route Control	1	0											1	0	0.5										1	0	0.3
1.2 Altitude Control	15	13	1	1	6	6			1	1	3	3	26	22	13.9	1	0					1	0	0.8	27	22	8.1
1.3 Clearance Control	6	6			1	1			1	1	3	3	11	11	5.5										11	11	3.3
1.4 Air Files	1	1											1	1	0.5										1	1	0.3
1.5 Speed Control	1	0											1	0	0.5										1	0	0.3
2. Air Traffic Control Support																											
2.1 Position Information	65	59	9	7	13	11	1	0	37	37	23	23	148	137	73.6	14	10	19	15	6	0	39	25	29.5	187	162	56.2
2.2 Altitude Information	63	58	8	6	13	11	1	0	37	37	23	23	145	135	72.1	14	10	17	13	6	0	37	23	28.0	182	158	54.7
2.3 Route Information	2	1											2	1	1.0										2	1	0.6
2.4 Speed Information	2	2	1	1									3	3	1.5	2	2	1	1	1	0	4	3	3.0	7	6	2.1
3. Advisories																											
3.1 Destination/ETA	13	12							11	11	4	4	28	27	13.9	15	9	22	17	15	0	52	26	39.4	80	53	24.0
3.2 Endurance/Fuel on Board	18	18							8	8	1	1	27	27	13.4	13	8	11	8	31	0	55	16	41.7	82	43	24.6
3.3 Aircraft Status	1	0											1	0	0.5			2	0			2	0	1.5	3	0	0.9
3.4 General Weather									1	0			1	0	0.5			2	0	4	0	6	0	4.5	7	0	2.1
3.5 Specific Weather	36	36	2	2					9	9	1	1	48	48	23.9	5	3	7	5	3	0	15	8	11.4	63	56	18.9
3.6 Aircraft Traffic																		1	0			1	0		1	0	0.3
3.7 Airport Status							1	0					1	0	0.5										1	0	0.3
3.8 Altimeter																1	0					1	0		1	0	0.3
4. Operational Control																											
4.1 OOOI Report											4	2	4	2	2.0	7	6			62	0	69	6	37.1	73	8	15.9
4.2 Airplane Number																4	3	2	2	9	0	15	5	11.4	15	5	4.5
4.3 Maintenance Services																		6	4	2	0	8	4	6.1	8	4	2.4
4.4 Aircraft Load																				1	0	1	0	0.8	1	0	0.3
4.5 Cabin Services							1	0					1	0	0.5										1	0	0.3
4.6 Passenger Services																		3	2			3	2	2.3	3	2	0.9
4.7 Flight Conditions	2	1											2	1	1.0					1	0	1	0	0.8	3	1	0.9
5. Communications Incidents																											
5.1 No Contact	1	0									2	0	3	0	1.5			4	0	6	0	10	0	7.6	13	0	3.9
5.2 Radio Equipment Check	3	0			1	0	1	0	2	0	1	0	8	0	4.0										8	0	2.4
5.3 SELCAL Check	13	0	2	0	2	0	1	0	3	0	6	0	27	0	13.4	6	0	4	0	5	0	15	0	11.4	42	0	12.6
5.4 Transfer of Control/Frequency Change							2	0	6	0			8	0	4.0	1	0					1	0	0.8	9	0	2.7
5.5 Relayed Messages							2	0			2	0	4	0	2.0	2	0	5	0	1	0	8	0	6.1	12	0	3.6
5.6 Ground-to-Ground Interchanges											3	0	3	0	1.5										3	0	0.9
Number of Messages	90		9		19		5		44		34		201			30		33		65		132			333		
Number of Aircraft	36		8		8		5		21		22		90			21		26		50		97			186		

NO - Number of message occurrences. RB - Number of occurrences with readback.

Table 5

MAJOR RADIO COMMUNICATION FACILITIES

Name	Areas Covered	Provider
Gander	Provides HF and VHF radio contact with NAT aircraft--primarily in Gander Oceanic FIR.	Transport Canada
Shannon	Provides HF (and limited VHF) radio contact with NAT aircraft.	Irish Ministry of Tourism and Transport
Reykjavik	Provides VHF and HF radio contact with northerly NAT aircraft. (Some aircraft in this area talk directly to controllers who have radar.)	Iceland but financed partly by ICAO agreements among other Provider States
Santa Maria	Provides HF and VHF radio contact with NAT aircraft, primarily in Santa Maria Oceanic area.	Portugal
New York	Provides HF and VHF in Caribbean (primarily in western area in Houston oceanic) and southern NAT.	ARINC, Inc. via FAA agreements
San Juan	Provides HF in southern NAT and eastern Caribbean.	ARINC, Inc. via FAA agreements
Oakland	Provides HF in CEP region.	ARINC, Inc. via FAA agreements
Honolulu	Provides HF in major portions of the Pacific.	ARINC, Inc. via FAA agreements

Other locations for which only limited data was available at this writing are:

Havana (Cuba); Port-Au-Prince (Haiti); Santa Dominge (Dominican Republic); Kingston (Jamaica); Merida (Mexico); Piarco (Port-of-Spain, Trinidad and Tobago); Maiquetia (Caracas, Venezuela); Curacao (Netherlands Antilles).

It is unknown whether these areas have specific communication facilities or operate directly with controllers.

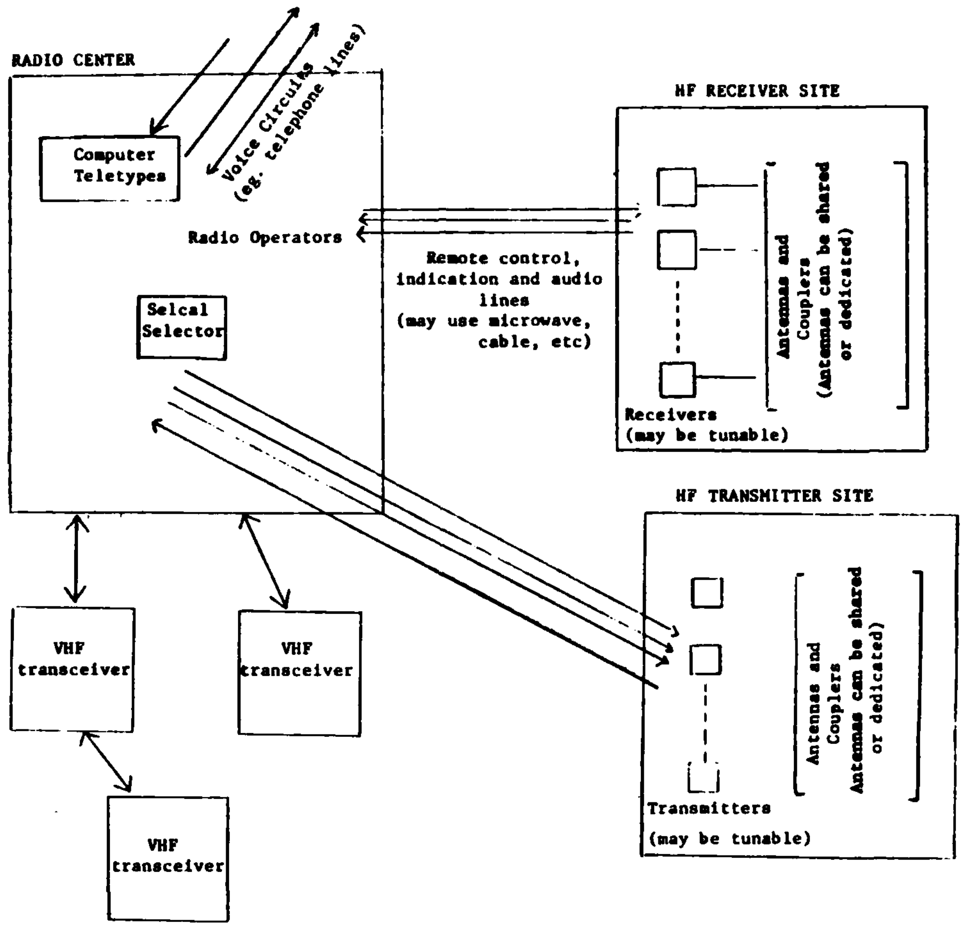


FIGURE 4 TYPICAL RADIO COMMUNICATIONS FACILITY

Antennas may be tuned to the proper frequency via couplers where physical dimension is hard to alter or broadband antennas (such as log-periodics) may be used. Antennas may be shared by several receivers but it is often more efficient to dedicate an antenna to a single transmitter.

HF equipment used in any given ground station tend to vary slightly in their characteristics. For example, some transmitters and receivers are tunable whereas others operate at fixed frequencies. Some receivers can automatically switch between SSB (A3J) mode and A3H based on incoming signal characteristics, whereas others operate in a fixed mode which may be manually switched. Specifications for particular ground based equipment can be obtained from several manufacturers.

The siting of ground HF station antennas can have a significant effect on coverage (as a function of frequency). In the NAT and CEP there is considerable redundancy in mobile coverage provided by various ground stations and a point-to-point communications system that allows any ground station to communicate with (and hence relay to) any other facility messages that are not heard elsewhere.

VHF transceivers (whether local or remote) are generally implemented so that only 1 or 2 frequencies (often including the emergency 121.5 MHz) are available at a given site. The high frequencies involved require small antennas and output power is on the order of 100 W. Occasionally, several VHF transceivers are all linked on one remote line as shown in Figure 4.

The size of any ground station is a function of the following:

Number of aircraft processed per unit time.

Number and type of messages that are transmitted.

The distribution of messages between HF and VHF.

The requirement (if one exists at a station) to provide meteorological information for aircraft in flight (VOLMET) broadcasts.

The number of frequencies to be monitored.

The reliability and type of equipment available for communications.

Stations vary in staffing size from two man operations (per shift) to stations such as Shannon which may have eight radio operators per shift.

A radio operator at a ground station typically uses a single frequency to listen to and talk to an aircraft. Other frequencies are simultaneously monitored in case aircraft try to call on those. When an operator is "working" several aircraft on a frequency, he can use a

device called SELCAL. Properly equipped aircraft can tune their radios to an operator-assigned frequency and then set SELCAL (discussed in Section 2.2.2) devices to respond to a radio operator-assigned code even when the aircraft's audio output is shut off. The radio operator initiates codes (via push buttons) for the aircraft with which he wishes to speak, thereby alerting the aircraft crew.

2.2.4 Airborne Equipment

Typical aircraft HF installations consist of:

(1) Two HF transceivers capable of SSB operation.

(2) SELCAL detector which can be used with either VHF or HF radios.

(3) One or more HF antennas and couplers.

Specifications for a typical aircraft transceiver, capable of operating in SSB and compatible SSB (A3H) mode over all HF frequencies are contained in ARINC specification 559a. SELCAL equipment can be used on HF or VHF radios. HF antenna mounting and maintenance present a minor problem for air carriers, because only small dimensions are available for HF antennas mounting, and couplers must be used to tune antennas. It was learned from airline personnel that some aircraft models (e.g., Boeing 747s) had recurring HF antenna problems that were overcome by design modifications and/or alteration to maintenance procedures.

2.2.5 Aeronautical Mobile Communications Message Flow Description

The information flow which takes place between aircraft and ground has been analyzed according to communication types in a NAT study (ref. 8). These message types involve joint uplink and downlink information flow and are named according to aeronautical function. Table 6 shows the message types and the relative amounts of (voice) channel time that they occupy. The rational for this particular information flow is not well established, although statistics concerning the flow itself have been highly developed.

Position reports consist of HF voice reports of aircraft identifier, position, time, altitude, and expected time and place of the next reporting point, and readback by the ground facility. The reports are initiated by aircraft at prespecified waypoints. In the NAT Organized Track System (OTS) tracks this is every 10 degrees of longitude. The position report is typically typed into the AFTN system by radio operators (to be sent to ATC centers and to company offices) and/or telephoned to controllers. There is, on the average, a 4 min or so lag between the time an aircraft crosses a reporting point and the time a message is completely received at the radio facility and turned into hard copy.

Table 6

MESSAGE DESCRIPTIONS

Message Type	Total Channel Occupancy Time (%)	Average Length (s)
Position reports	65.1%	42
SELCAL checks	7.6	17
ATC messages	6.8	13
Ground/ground interchanges	3.0	
Frequency change instructions	2.9	4.5
MET (meteorological) information	2.7	10.5
Company information		
Associated with position reports	1.6	9
Not associated with position reports	2.1	

Figure 5 details some delay figures from the annual study done in 1978 (ref. 8). The figure shows that delays can build up to averages of 7 min or so. It appears that, in the current environment, a channel for a given station can support up to 25 position reports in an hour as did Shannon on 2945 KHz on August 2, 1978 between the hours of 0400-0500 (ref. 5). The total usage of the frequency that hour was about 40 position reports.

Other categories of reports (nonposition reports) in Table 6 often occur as adjuncts to position reports and hence arrive with great regularity. The function of the SELCAL check is self-evident. ATC messages consist of clearance data including requests for changes to flight clearances (such as climbs to higher altitudes) and ATC responses to requests. Ground interchanges involve use of air/ground frequencies by ATC or radio facilities to expedite message flow when parts of an aircraft report are lost by one station. Frequency change instructions are ground-to-air messages to switch to another (VHF or HF) frequency. MET reports consist of observations of meteorological conditions made by aircraft and/or requests by aircraft for special data not obtained from VOLMET broadcasts, the availability of which obviates the need for extensive weather on other frequencies

The quality of air/ground VHF communications (where line of sight situations exist) is always good. Discussions with selected NAT and CEP HF communicators revealed no major problems. Some miscellaneous notes (e.g., ref. 9) indicate that there has been historical unreliability in HF which is overcome by aircraft-to- aircraft relay (via HF or VHF) or by simply accepting that occasional gaps in position reports can occur. Due to the sparsity of available data, however, no conclusions can be drawn concerning HF reliability. No loss of position reports has been noted in major studies of the system (e.g., ref. 8).

2.3 Aeronautical Fixed Communications

Many types of facilities are interconnected via a network of communication channels that include HF point-to-point channels, cables (land and marine), satellite links, etc. Some of these physical channels are used for both voice and data (teletype) while others are dedicated. Various switching mechanisms are used so messages can be routed throughout the world. This system is fairly well developed in the NAT and CEP areas and partially developed in the CAR and many other parts of the world.

The need for fixed communications is sensitive to the siting of communication stations, ATC facility locations, and FIR boundary locations relative to traffic flow patterns. There are many examples where local conditions have led to system alterations which minimize communications. In the San Juan oceanic region, for example, a notch has been cut in the southeastern corner to eliminate the need for air-to-air and ground-to-air message flow that would otherwise be necessary for aircraft clipping the San Juan boundary when flying between Piarco and Santa Maria FIR.

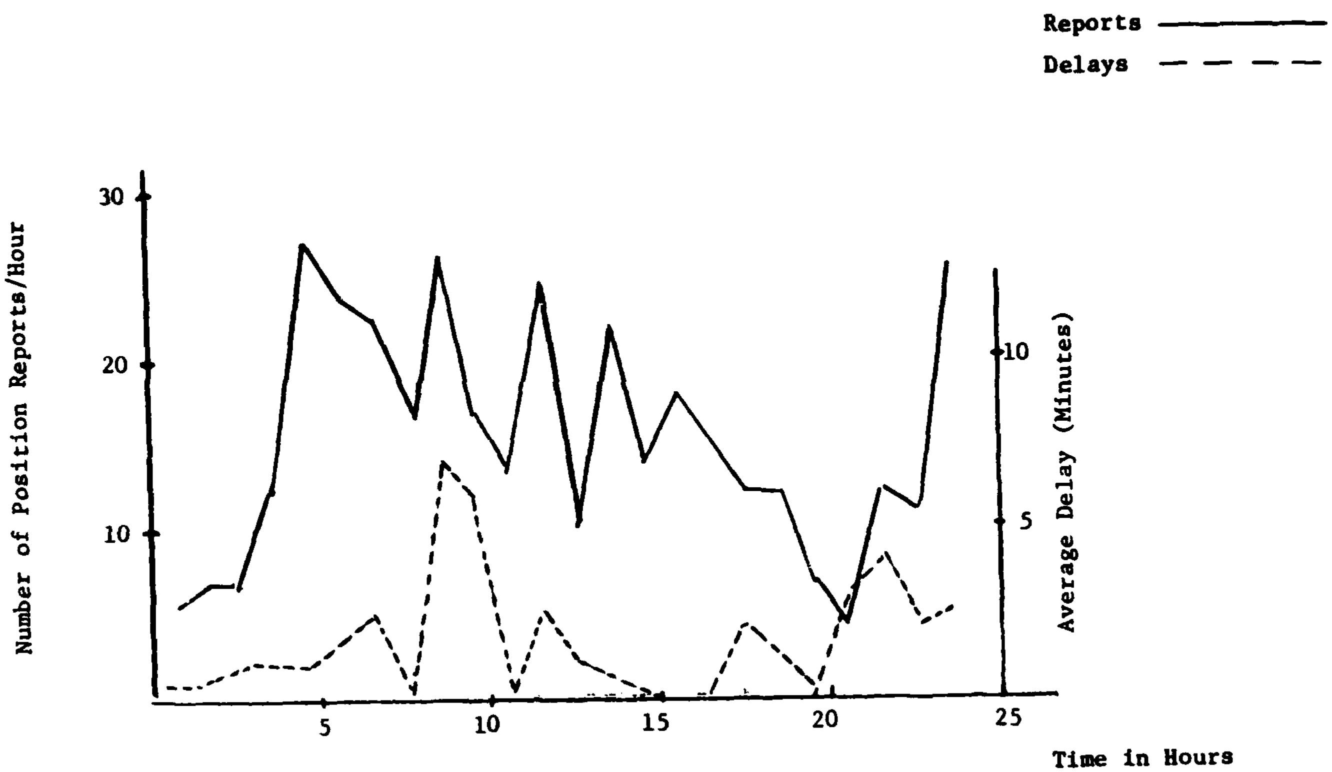


FIGURE 5 ANNUAL H/F DATA COLLECTION AUGUST 2, 1978
COMPARISON OF NUMBER OF POSITION REPORTS ON FREQUENCY 8945 AND MEAN DELAY

The physical channels and switching equipment are implemented and maintained by the nations in which they lie. In the case of oceanic cables, or other channels crossing international boundaries, channel design is by mutual agreement and cost is absorbed by each separate country, bearing whatever cost is locally imposed for a half channel. ICAO agreements are used to allocate the cost of some channels. The network is suggested by ICAO Regional Air Navigation meetings and published in the regional air navigation plans.

Fixed communications have been categorized into the AFTN and ATS direct speech circuits. The latter speech circuits are to provide direct controller-to-controller voice circuits between all adjacent FIR in the case tactical actions are required. AFTN is designed to handle specific sorts of data such as flight plan forwarding and the forwarding of aircraft position reports from a radio facility to all interested parties including ATC facilities, air carrier offices, etc.

Both voice and AFTN data can be sent over the same physical channels and this is often done in the interest of economics. There is a good deal of formal description concerning AFTN transmission in Annex 10 of the convention of ICAO. There is no central repository of data on all the physical links and interfaces that are used to transmit data or voice.

Tables in the ICAO regional plans outline the functional channels in these networks that either exist or are desired. The function and structure of the AFTN and ATS networks are being studied by an ICAO panel of the Air Navigation Commission. This committee is called ADISP (Automated Data Interchange Systems Panel). It has been active recently in defining transmission procedures using packet data transmission, higher data rates, new coding techniques etc.

3.0 THE NAT

Each FIR in the NAT has its own civilian HF communication station for air-to-ground communications with aircraft. In addition, military services and some private organizations have HF communication centers which cover the Atlantic. All the civilian communication centers have associated ATC centers. VOLMET information (weather and other data of interest to aviation) is broadcast on assigned HF frequencies over the NAT. The six major FIR communication stations (Gander, Shannon, Reykjavik, New York, Santa Maria, and San Juan) coordinate the use of overlapping frequencies to facilitate their major functions.

Almost all air carriers with significant NAT traffic carry dual HF radios and operate in SSB receive and transmit mode (A3J). In addition, these radios contain a detection mode for A3H (full carrier single sideband) which can be used to detect SELCAL signals transmitted by communication stations.

Based on a survey of major users in the NAT, the current HF radio equipment works well. Several areas of concern were uncovered:

(1) Some difficulty in communicating on very northern routes with HF, even with modern SSB equipment in wide-body aircraft.

(2) Some aircraft may not be communicating as required. This can include military and civilian aircraft which for political or other reasons do not communicate.

3.1 Gander Communications Station

The Gander communications station is described in some detail in Figure 6 and in Tables 7 and 8. Figure 7 shows the portions of NAT, which, at 30,000 ft have VHF coverage. Other areas are covered by HF. In the case of Gander, aircraft operating within VHF range use VHF for voice and SELCAL. Aircraft reporting to Gander over HF around the 30 degree dividing line between Gander and Shannon are generally overheard by both stations and messages to either station are acknowledged by both (ref. 10).

The Gander communications station transmits all position reports or other data of interest to the Montreal ADIS computer which can, in turn, send information throughout the AFTN network. On data collection days-- July 28, August 2, and August 4, 1978, Gander handled, on HF, totals of 684, 687 and 622 position reports. On these days it had 454, 418 and 504 VHF reports. There are two VHF positions at Gander and seven HF positions. It appears that VHF reports constitute about 40 percent of

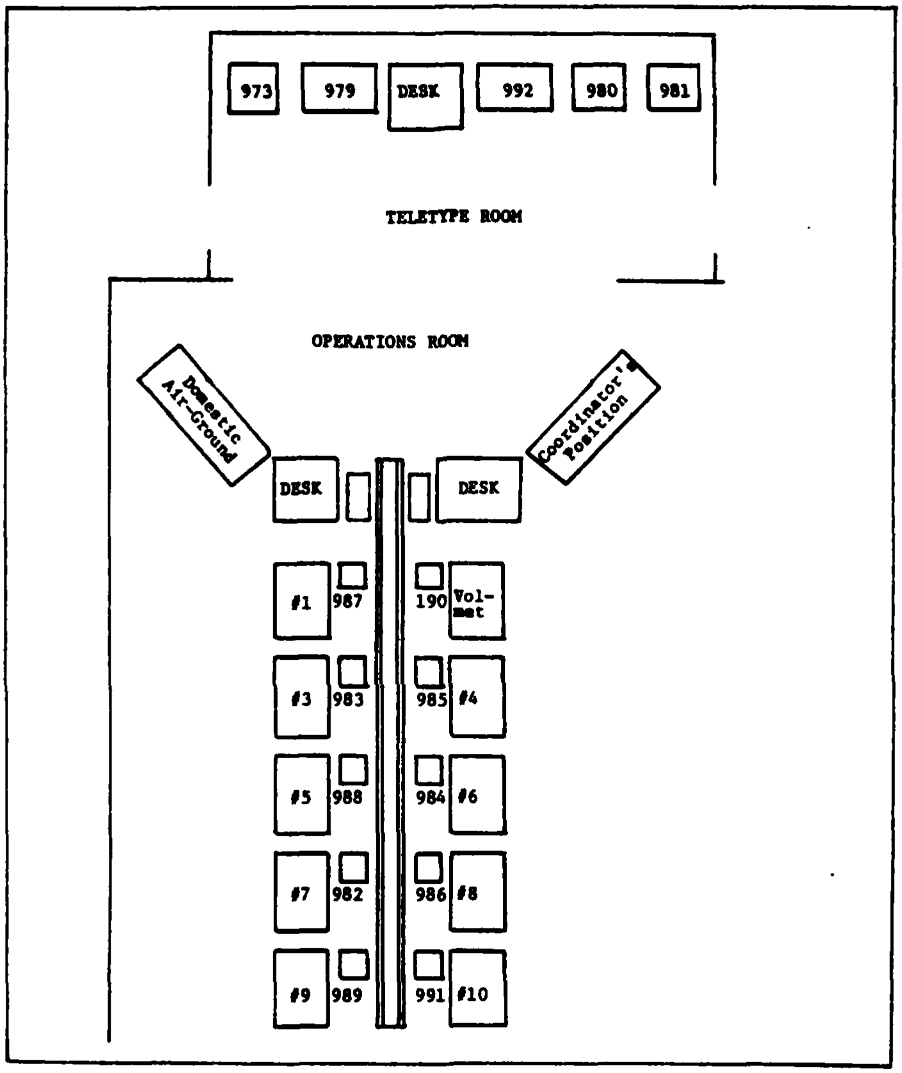


FIGURE 6 GANDER COMMUNICATIONS CENTER LAYOUT
(Downtown, Gander, Newfoundland)

Note: For explanation, refer to Table 8 .

Table 7

GANDER COMMUNICATIONS CENTER
TECHNICAL SUMMARY

HF EQUIPMENT

Aeronautical Mobile Transmitters:

Number and Type: 14 Northern Electric CRC/FRT 1,002 5 kW transmitters.

Antenna: Each has its own 1/4 wave tuned dipole.

Characteristics: All switchable between A3H and A3J remotely; each operates at fixed frequency, normally 12 used at once, normally run at 2 kW.

Comments: New transmitters will be purchased to replace those of Northern Electric.

Backups: 4 tunable (one each in 2.9, 5.6, 8.9, and 13.3 MHz band) Northern Electric, same as above, one usable at a time.

Aeronautical Mobile Receiver:

Number and Type: 14 Canadian Marconi XH-14 receivers.

Antenna: All use a single vertical antenna through multicoupler. (A small vertical backup is also available.)

Characteristics: All switchable between A3H and A3J remotely, each at fixed frequency.

Backups: Spare XH-14 receivers available.

VOLMET Transmitters:

Number and Type: 4 TMC Technimatic HFLM 10K 10 kW transmitters.
Antenna: 4 separate verticals.

Characteristics: A3H mode, fixed frequency, normally run at 1.5 to 2 kW.

Backups: 4 RCA AVT-22B transmitters, fixed frequency, operating A3 mode.

Comments: New transmitters planned.

Table 7 (Concluded)

VHF EQUIPMENT (OPERATED FROM GANDER)

Transceivers and Location
2 at Gander (126.9, 127.11).
1 extended range-Fredriksal 127.9.
1 extended range-Prins Christian Sund 127.9.
1 extended range-St. Johns 126.9.

COMMUNICATIONS TO OTHER FACILITIES

Lines to external facilities include:

* 9 send teletype lines to ADIS computer (AFTN link) in Montreal.

* 1 receive NOTAM unit.

* 1 send and receive main circuit to ADIS.

* 2 receive only circuits from ADIS for flight plans and position reports.

* telephones to GANDER ATC supervisor.

Note: Normal position reports transmitted from radio operators to ATC via teletype circuits. Clearance requests, etc., made via telephone between operators and ATC.

Table 8

GANDER COMMUNICATIONS CENTER SUMMARY

TELETYPE ROOM

Circuits

973 - Receive only - NOTAMS.
979 - Send and receive - main ADIS (admin. messages, service messages, company messages, etc.).
992 - Send and receive - manual circuit, Gander and St. Pierre only.
980 & 981 - Receive only - flight plans, position reports.
Telephone: 256-3842.

OPERATIONS ROOM

* Domestic air/ground frequencies 121.5, 122.1 (Receive only) 122.2, 126.7, 243.0, VOR, NDB.

* Monitoring VOR, ILS, QX Q WS NDBs, TACAN, VOT.

* Receivers 1 HF TUNABLE, 1 VHF TUNABLE.

* Telephone 256-3826, and Hotline to tower.

This position processes company traffic and flight strips for TWA and all military flights.

COORDINATOR'S POSITION

Telephone

256-4421, and Hotline to ATC Supervisor.
Intercom, to all ICAO positions
Controls the information on closed circuit TV and handles all traffic and flight strips for all aircraft except TWA and Military.

Files all international air/ground traffic.

Table 8 (Continued)

POSITION #1

Frequencies

126.9 Gander and St. John's.
127.1 Gander and St. Anthony.
127.9 Greenland.

VOLMET

* Transmits 3001, 5652, 8868, 13271 KHz.
  Broadcast times H + 20 to 30 and H + 50 to 60.
  Monitors above frequencies during broadcast times.

* Teletype - MET circuit 190 receive only.

POSITION #3

* Family "D"

  Transmit and Receive 8910, 5624, 2868 kHz USB & DSB.
  127.1 MHz Gander and St. Anthony.
  126.9 MHz St. John's VHF rarely used this position.

POSITION #4

* VHF

  126.9 Gander and St. John's.
  127.9 Greenland.
  5638 KHz - Used only to take over during busy periods when position #8 closed.

POSITION #5

* Family "B"

  Transmit and Receive 13288, 8889, 5673, 2987 USB.

POSITION #6

13288, 5673, 5624, 126.9 Gander.
Used 16 hr per day for peak periods.

Table 8 (Concluded)

POSITION #7

* Family "C" 8854, 5638, 2945 USB.

POSITION #8
periods
13328, 8854, 5638.
Used 16 hr per day for peak periods.

POSITION #9

* Family "A"
13328, 8945, 5610, 2931 USB.

POSITION #10
5673, 5610, 5624, 2931.
Used 16 hr per day for peak periods.

Note: All air/ground positions equipped with hotlines to ATC and intercom to coordinator's desk.

Teletype Circuits 987, 983, 988, 982, 989, 985, 984, 986, 991 are all half duplex. All air/ground traffic copied on teletype and fed directly to DS714 computer in Montreal. Positions 4, 6, 8, 10 open 16 hr per day for peak periods during summer. Position #10 closed from November to May. Remainder of positions open 24 hr.

Traffic belt is used to carry hard copies of traffic to coordinator's desk for filing.

Each international air/ground position has a TV monitor controlled from the coordinator's position. This contains general information that changes constantly, e.g., equipment outages, ATC frequencies, traffic for aircraft, etc.

Operators use teletypes to relay position reports to ATC, and to telephone for clearance relays.

Estimated annual staffing level (e.g., radio operators, technicians--50 people total including 40 radio operators.

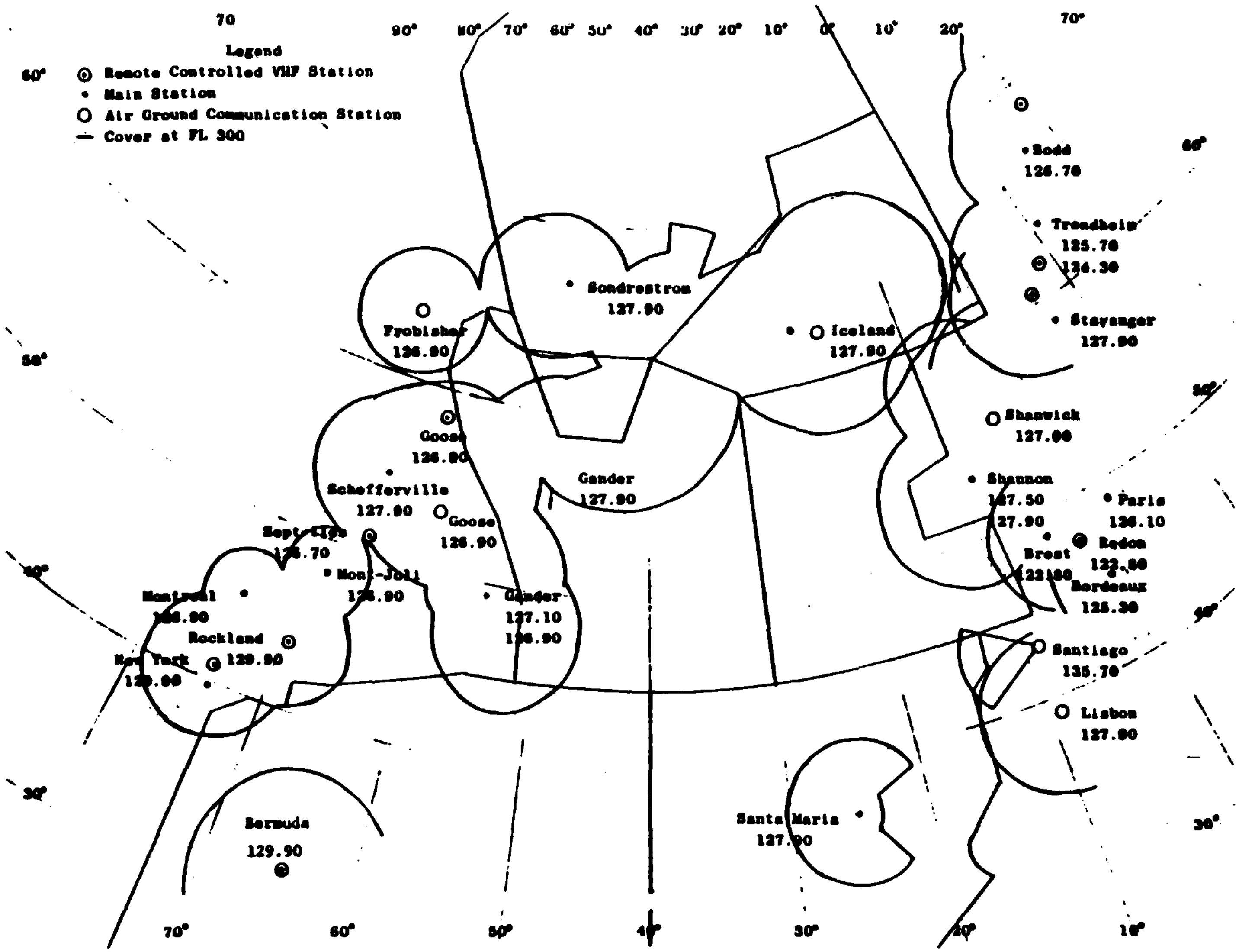


FIGURE 7 ESTIMATE OF VHF COVERAGE OF THE NORTH ATLANTIC AT 30,000 FEET

the total but require only about 20 percent of the workload. On these days, 480, 426 and 424 jet aircraft crossed the 50 degree West border of Gander. Assuming most of these used the Gander communications station, there were an average of 2.5 position reports/aircraft to Gander radio communicators.

Costs of operating this facility were estimated to be on the order of US$ 2,800,000 for calendar year 1978. These costs were recovered by user charges.

3.2 Shannon Communications Center

The Shannon communications station parallels that of Gander. There are several principal differences, however. For example, the Shannon station communications center, located in Ballygirreen, Ireland, some 10 km or so from Shannon, Ireland, is operated by a different nation than its associated ATC center in Prestwick, Scotland which is operated by Great Britain. Further, Shannon has considerably less VHF communications than Gander.

An inventory of Shannon equipment was not available at this writing. It is known, however, that Shannon has transmitters and receivers from six different manufacturers. The remote antenna facility located at Urlanmore has 42 antennas (3 rhombics, 32 quadrants, 6 triple folded dipoles, 1 broadband and 2 inverted "L"s). These service the four NAT families, VOLMET and several point-to-point teletype links. There are typically eight radio operators working on busy shifts in addition to maintenance and other support staff. Operators key almost all ATC information into teletypes. These teletypes have access to Prestwick via two direct circuits and via AFTN circuits to London. The latter circuits are used for transmitting position reports. The direct circuits are used for time critical messages such as relay of requests for clearance changes.

Shannon also operates one general purpose VHF frequency. In 1978, Shannon serviced 102,156 flights and processed 413,806 messages. Total revenue was approximately US$ 1,888,700. About 7 percent of Shannon's air-to-ground volume was handled by VHF.

3.3 New York Communications Station

The New York Communications station is operated by ARINC. The layout of the Center is shown in Figure 8. Notice that generally it has 5 operators allocated to communications that are of interest to this project. Two of these deal primarily with CAR communications which were recently moved from Miami to New York. The actual ATC communications traffic handled by New York for the NAT is roughly 1/4 of that handled by Gander or Shannon.

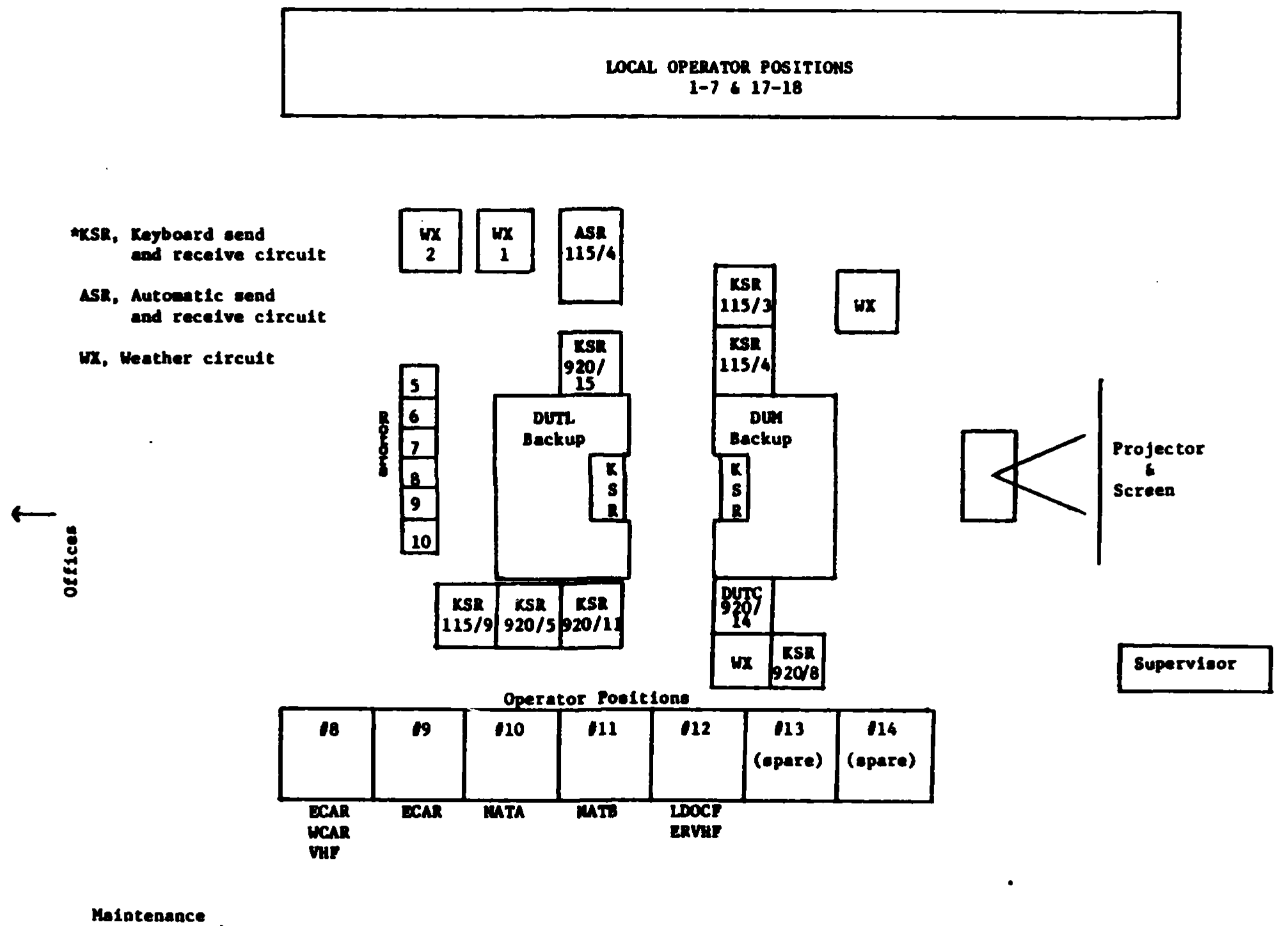


FIGURE 8 NEW YORK ARINC COMMUNICATIONS CENTER, ISLIP, NEW YORK

New York is the only ARINC facility that communicates with its associated ATC facility using teletype as a standard reporting tool. All position reports are teletyped to the New York Oceanic controllers. Data is input via CRT devices which permit convenient editing and addressing of information. This facility, like the San Francisco facility, is dominated by equipment and personnel who operate ARINC's domestic VHF company communications system. Table 9 summarizes New York's equipment.

On a typical day this center will handle approximately 250 position reports from NAT traffic. ARINC charges FAA for services based on a per message basis (which is not equivalent to a per contact basis). In calendar year 1978, ARINC billed the FAA for 181,980 message transactions for NAT communications. New York also handled (in 1978) 43,211 message transactions in the CAR area which is now served by New York transmitters and receivers. These contacts were billed at US$ 4.22 per transaction (for a total of $767,955 for the NAT and $182,350 for the CAR.

3.4 Reykjavik (Gufunes) Communications Station

This facility is located in Iceland at Gufunes and operated by the Directorate of Civil Aviation under an agreement of joint financing (ICAO Doc. 7727-JS/564). The United Kingdom invoices for user charges for these facilities.

Table 10 gives some inventory information for Reykjavik. In addition to providing air-to-ground communications, this facility provides marine services as well as manual switching of AFTN data. Air-to-ground services employ a staff of three to five persons per shift; AFTN services employ a similar number of staff. Each shift also requires some supervisory personnel. Under the ICAO agreement the station can have a staff of 48 persons.

On 3 sample days this station averaged 167 HF position reports and 263 VHF reports. Reykjavik's HF reports are heavily concentrated at three frequencies (8854 KHz in family C, and 5624 and 8910 KHz in family D).

Flights occasionally will utilize the Greenland/Iceland crossing of the NAT when they are operating without HF coverage. At high altitudes this route can provide almost continuous VHF coverage.

Costs for operating Gufunes in 1978 were US$ 1,204,466. This includes the costs for personnel for AFTN switching but does not include major cable rental costs.

3.5 Santa Maria Communications Station

Santa Maria has about 1/2 of the message loading of Gander or Shannon. Services are provided by the Airports and Air Navigation Public Enterprises (ANA/EP). Although Santa Maria currently operates on HF Families A, B and C, Family C will soon be dropped due to low traffic

Table 9

NEW YORK ARINC COMMUNICATIONS STATION
TECHNICAL SUMMARY

HF EQUIPMENT

Aeronautical Mobile Transmitters

Number and Type: 8 Aerocom model 1330 5 kW transmitters dedicated to NAT-A, NAT-B, E-CAR, WEAR, north and east long-distance operational control, a Cuba circuit, offshore drilling circuit.

Antennas: Riverhead, Long Island, NY; each of above (except for offshore 4654 KHz) has a Granger model 1702 with a beamwidth of 63 degrees and a gain of 11.5 NAT-B at 55 degrees, ECAR at 177 degrees, WEAR at 202 degrees, Havana circuit at 102 degrees.

Characteristics: Six channel, remotely switchable between A3J (or ASA) and A3H.

Backups: 3 Aerocom 1330 backups for NAT-A, NAT-B, ECAR, Aerocom 1311 for WCAR (1 kW located at Miami International Airport, FL.

Aeronautical Receivers

Number and Type: 21 Kahn RBI-A1 receivers tuned to NAT-A NAT-B, ECAR, WCAR; Aerocom 2210 models and McKay-Dymek used in other frequencies.

Antenna: Located at Southhampton, Long Island, NY; each family uses directed fan, rhombic or hygain (LP1017) antenna pointed as follows: NAT-A-102 degrees, NAT-B-52 degrees, ECAR-168 degrees, WCAR 202 degrees.

Characteristics: The Kahns are automatic bimodal receivers, which can detect and switch between A3J or A3(AM) or A3H.

Backups: Primarily McKay-Dymek DR-336 tunable receivers; modes unknown.

Table 9 (Concluded)

VHF EQUIPMENT

Transceivers and locations; 2 ER pointed at 92 degrees and 110 degrees from Southampton, Long Island; and Atlantic City, New Jersey. (129.9 MHz). Also at Sidney, Nova Scotia; Rockland, Main; Sept Isles; 5 ERVHFs for Gulf of Mexico: Brownsville, Texas (147 degrees), Lake Charles, Louisiana (179 degrees), Grand Isle, LA. (155 degrees), Venice, LA (170 degrees), Tampa, FL (235 degrees) all on 129.4. Miami and other areas have conventional VHF.

Communications to other facilities: ARINC's electronic switching system (ESS) which is connected to AFTN. Direct telephone lines to each oceanic controller. There is a direct ESS line to New York ATC on which all position reports are teletyped.

Table 10

REYKJAVIK COMMUNICATIONS STATION
TECHNICAL SUMMARY

HF EQUIPMENT

Aeronautical Mobile Transmitters

Number and Type:	Two-10 channel 3 kW AM for Family D feeding "L" antenna and a rhombic directed at 308 degrees true.
	Two single-channel 5 kW, feeding horizontal dipoles serving Family D.
	Four single-channel 5 kW SSB with horizontal dipoles for Families B and C.
	Two six-channel 5 kW SSB feeding a broad-band inverted discone serving Families B, C, D; a rhombic directed at 072 degrees true for Families B and C.

VHF EQUIPMENT

Transceivers and Location

3 ER, one at Thorbjverin pointed at 230 degrees true with an output power of 800 W and one at H'afell pointed at 140 degrees true with an output power of 1,000 W. Another at Gagnheidi pointed at 110 degrees true with 1 kW output.

volume. The radio station at Santa Maria operates one ERVHF on 127.9 MHz which handles 8 percent of its position reports. The Santa Maria communications station and center occupy the same floor of a building.

On some sample days, the communications station averaged 435 position reports per day. The station is financed partly by the State and partly by Eurocontrol charges. At this writing exact charge information is not known. Eurocontrol charges are based on weight and distance. Long flights through the Santa Maria FIR would result in much higher costs than flights through other oceanic areas if they were billed on the Eurocontrol charges calculated for Portuguese overflight.

3.6 NAT-AFTN

The countries surrounding the NAT have extensive and well-developed international communication links which include cables, (marine and land) microwave links, satellite links, etc. Furthermore, the internal telephone communications in those countries are highly developed. These facilities have been used to provide a reliable AFTN.

Major message switching centers have been built in various countries which direct teletype information as required. These include facilities in Kansas City (U.S.), Montreal (Canada), Lisbon (Portugal) and London (UK). An outline of this system is shown in Figure 9. Note that these centers have been interconnected. The switching centers themselves radiate lines that often extend beyond the country they are located in. The lines interconnecting the switching centers and radiating from the centers are generally leased from common carriers. However, sometimes an HF teletype link will be operated between two points, such as the FAA-operated link between Lisbon and New York as part of a Kansas City link to Lisbon. (There is also a common carrier cable link.)

The message formats within most countries in the NAT involve 50 and 75 baud transmissions on leased voice-quality telephone lines, which generally have a 3 KHz bandwidth. Within the United States, a single voice line is often used to transmit 24 derived channels of digital information at 75 baud each by frequency multiplexing data onto the single line. Another common technique is to use a 3 KHz line to transmit voice and one or two data channels at 50 baud each at the higher frequencies. This is often called "speech plus" transmission and is used in the CAR as well as in some NAT lines.

A major international communications channel such as that between Kansas City and Montreal, both of which have sophisticated computer interfaces, operates with a format and speed arrived at by agreement between countries. In the Montreal-Kansas City example a 1,200 baud common carrier line ties the systems together. Secondary international channels are also connected to the major switching centers.

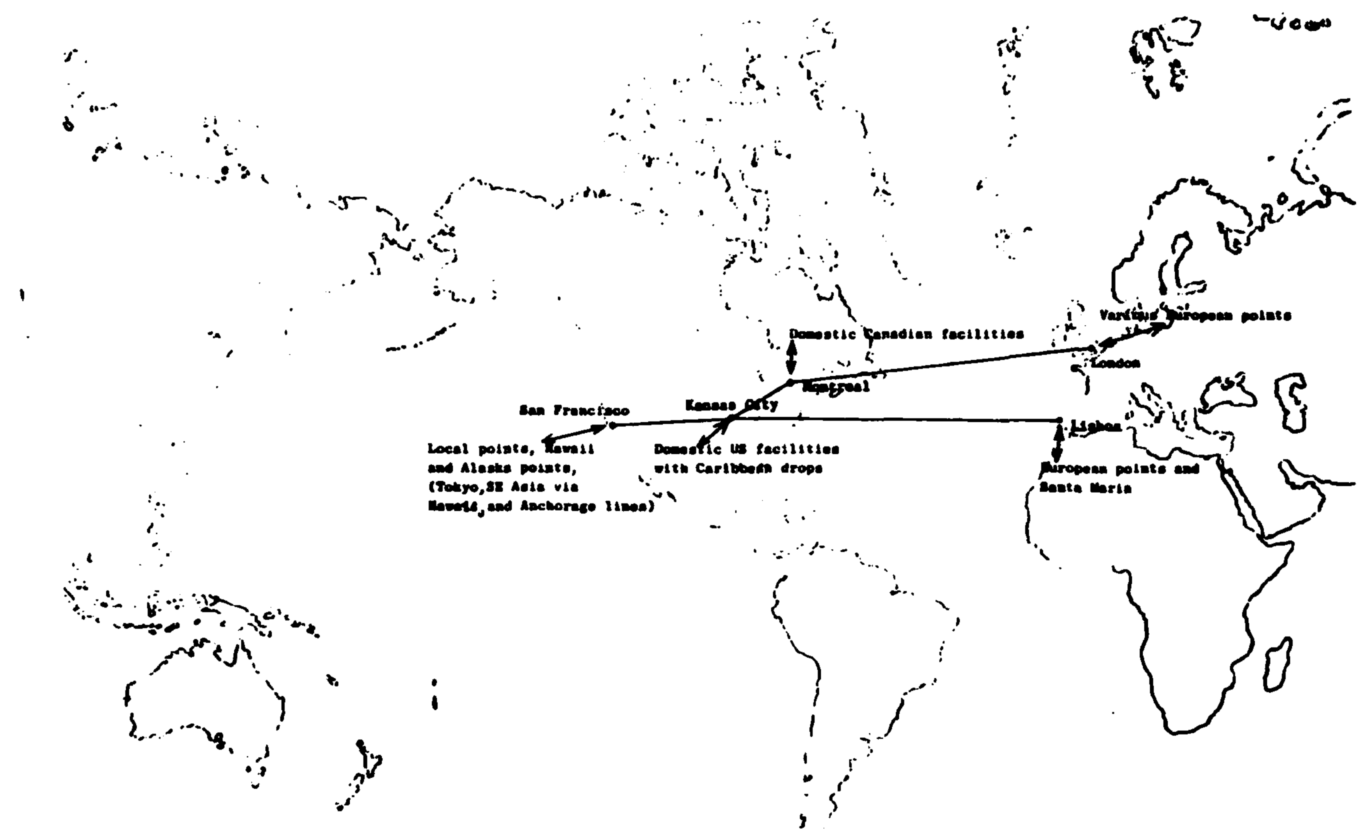


FIGURE 9 BASIC LINES IN THE AFTN NAT, CEP, AND CAR

Field equipment for AFTN input is often fairly old-fashioned teletype equipment with little facility for buffering data. However, single 75 baud lines use polling procedures to accept inputs from several devices simultaneously. In New York, for example, one of 24 lines can be used to poll teletypes from each of several airlines that may want to input flight plans.

Discussions with aircraft operators and providers of ATC services in the NAT have revealed no functional problems with AFTN in the NAT. Flight plans and other data sent across NAT AFTN facilities seem to be timely and accurate. The existing ICAO ADIS Panel is working to generate technical recommendations for the use of more advanced data interchange techniques.

The cost for AFTN is borne by the nations providing the communications channels over which data flows and normally recovered through user charges, or other means. A typical voice-quality Europe to North American line costs approximately $10,000/month to lease. Such a line between the United States and Lisbon, for example, would have its costs shared between the United States and Portugal according to local carrier tariffs. A transmission between, say, Gander and Santa Maria could be sent to Montreal, thence to Kansas City, thence to Lisbon, thence to Santa Maria, with each country or group within a country bearing its line costs. Gander could also send this message to Kansas City, thence to New York where an HF line direct to Santa Maria has two 50 baud channels.

3.7 NAT-ATS Speech Circuits

Many of the comments made regarding NAT-AFTN apply also to the ATS. Figure 10 shows some of the major ATS connections. Note that many connections are made by switching at various points. For example, if Gander wishes to speak to Santa Maria, it does so by getting a patch from New York ATC, which has cable service to Lisbon, which has an Intelsat channel to Santa Maria. Voice channels are more expensive for data transmission than data channels and are only used in circumstances in the NAT requiring tactical control. Examples of the latter type of control would be coordination of a step climb near the border of an oceanic sector or resolution of an emergency condition between controllers. No particular ATS problems were identified in the NAT with the possible exception of communications between Santa Maria and Prestwick due to HF link between Lisbon and Santa Maria.

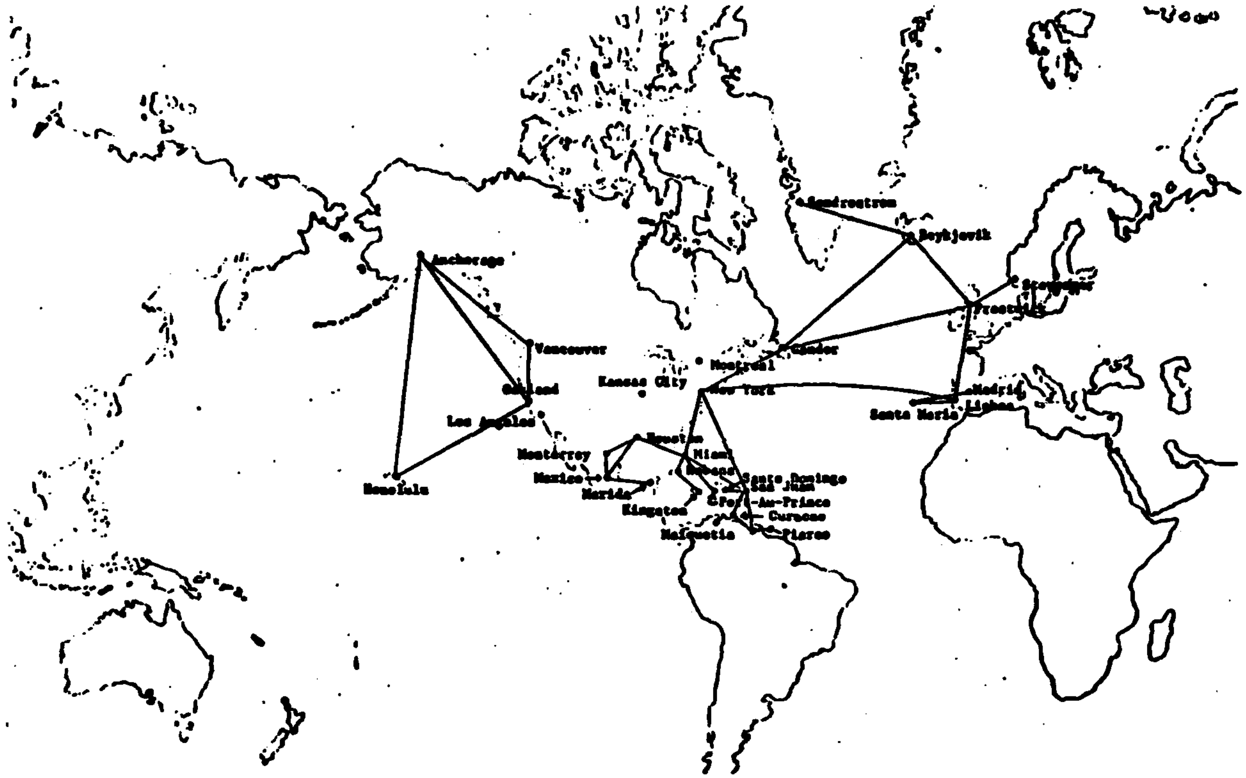


FIGURE 10 MAJOR ATS DIRECT SPEECH CIRCUITS

4.0 THE CEP

4.1 Introduction

This area is served primarily by ARINC stations in Foster City, California (near San Francisco but designated as "Oakland radio" on charts) and Honolulu. The two communication centers are very similar. ARINC centers mainly serve the domestic VHF company facility network with automated data-receiving terminals, which automatically route company messages to ARINC's Chicago computer facility. These terminals are part of a system called the ARINC Communication and Reporting System (ACARS). HF communications comprise only a small portion of ARINC's operation. All HF or VHF communications relayed to ATC facilities are paid for by the FAA as mentioned in the discussion of the New York ARINC.

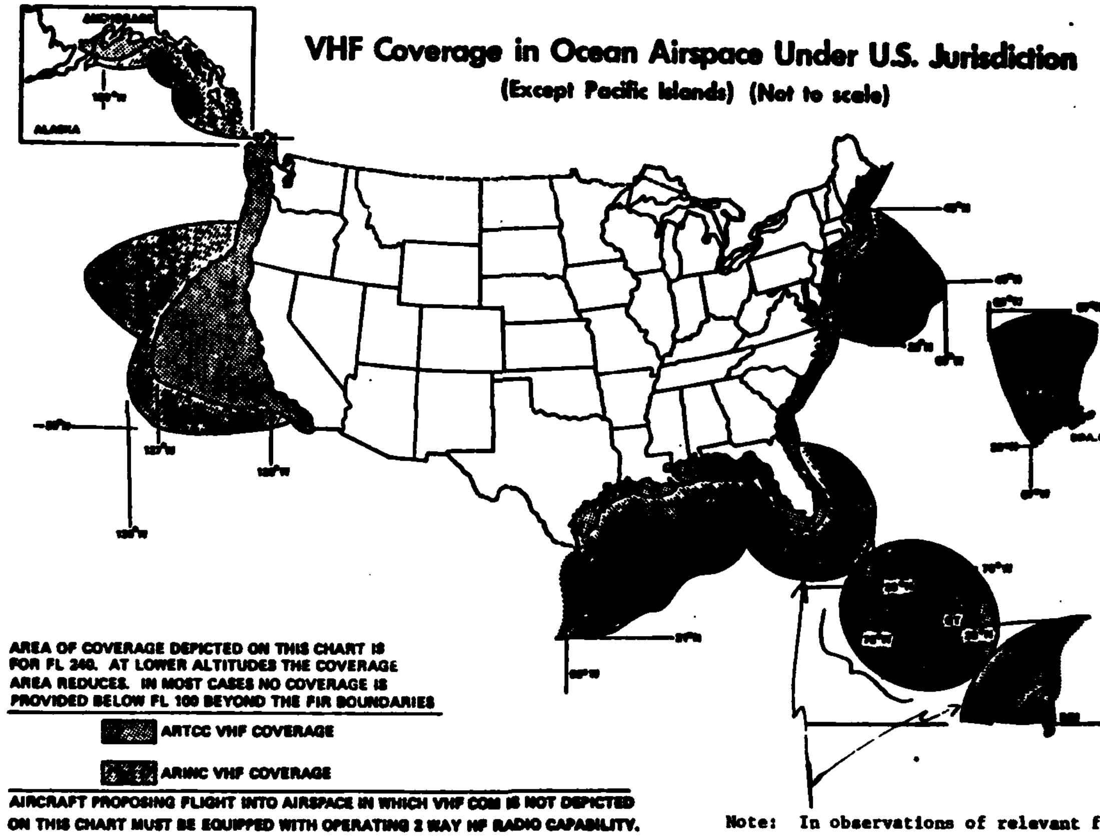
VHF coverage in and around the U.S. area is shown in Figure 11. Note that this figure shows coverage for 24,000 ft rather than the 30,000 ft shown for the NAT. VHF coverage for the Hawaii area corresponds closely to the radar coverage in that area. This is shown in Figure 12.

ARINC Oceanic facilities operate in close contact with their ATC counterparts. Position reports are both teletyped into the AFTN via a link through ARINC's electronic switching system (ESS) Chicago link, and telephoned to local ATC positions via voice links.

Discussions with controllers staffing the Oakland ATC center indicated that air-to-ground HF communications are important to maintaining safe and efficient operations, because Canadian, South Pacific, Oriental traffic, and organized tracks enter its area on tracks which could conflict with each other without clearance changes en route. Although this type of traffic constitutes several flights per day, it is perceived to be on the increase. As with the NAT, no data was available on air-to-ground communications reliability. There have been occasional periods where a band of frequencies in the Pacific was unusable due to man-made interference.

4.2 Oakland (Foster City) Communications Station

Figure 13 and Table 11 outline the HF facility that supports the Oakland Center. Generally two operators handle the workload on any shift but one to three may be used as communications workload varies. The HF portion of this facility is a small part of the total facility but has extensive equipment used to support domestic company needs. Much of this domestic need has been automated using ACARs.



Note: In observations of relevant facilities it appears that there exists VHF coverage by FAA in the entire San Juan Corridor by Eleuthra and Grand Turk VHF at these altitudes, although the advisory circular shows gaps filled in by ARINC.

FIGURE 11 VHF COVERAGE AREA DEPICTED IN FAA ADVISORY CIRCULAR 91-52 DATED 6/21/60

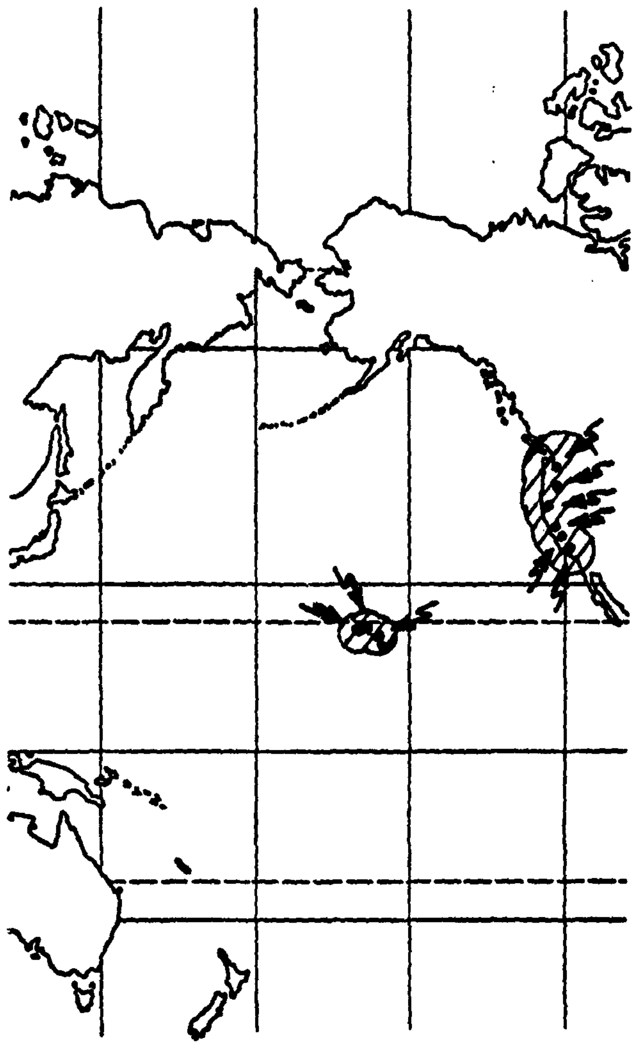


FIGURE 12 RADAR COVERAGE IN CEP WHICH (APPROXIMATELY) CORRESPONDS TO VHF COVERAGE IN HAWAIIAN AREAS

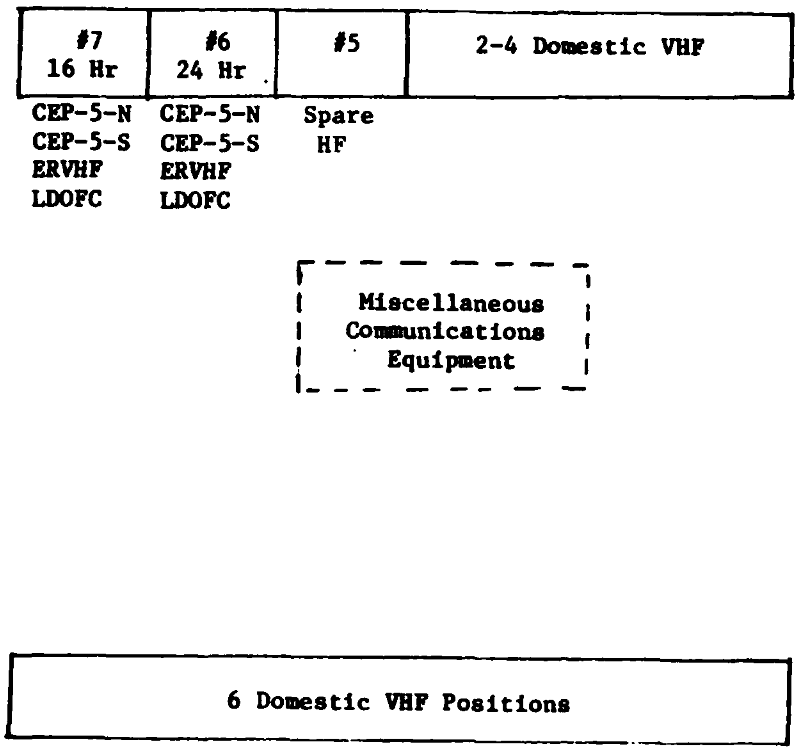


FIGURE 13 OAKLAND, CALIFORNIA (FOSTER CITY) ARINC RADIO CENTER

Table 11

OAKLAND ARINC COMMUNICATIONS CENTER
(Controlled from Foster City, California)

HF EQUIPMENT

Aeronautical Mobile Transmitters

Number and Type: 3 Aerocom 1330 5 kW transmitters.

Antenna: TCI model 502 LP with 61 degree bandwidth and 6 DB gain. CEP-55 frequencies pointed at 222 degrees, CEP-5-N frequencies pointed at 279 degrees, LDOCF at 222 degrees, in San Mateo County (Old Globe Wireless).

Characteristics: See Table 12.

Backups: 2 Aerocom 1311 1 kW with dipole antenna.

Aeronautical Receivers

Number and Type: 15 Kahn RBI-A1.

Antenna: Rhombic directed at 252 degrees, located on King Mountain in San Mateo County.

Characteristics: See Table 12.

Backups: McKay-Dymek DR-33C tunable at Foster City.

VHF EQUIPMENT

Transceivers and location: ERVHF toward 252 degrees from

San Francisco (131.95 MHz) and Santa Barbara, California, site.

Communications to other facilities: telephones direct to Oceanic ATC positions. Also, ESS connection to AFTN.

Radio operators at this center relay all position reports to the Oakland Center with voice telephone reports. No data is available on delays or other characteristics of this HF center, but observations reveal no significant differences from typical NAT centers. Data such as position reports are also teletyped into ARINC's own system for entry into the AFTN from whence that data is sent to carriers or other AFTN points.

Oakland invoiced the FAA for 106,728 messages in 1978. Of The 106,728 messages, 26,500 were VHF. These are presumed to be from the ERVHFs. Total cost for these services was US$ 450,392--mean of 292 messages per day. The bulk of the CEP traffic uses the organized tracks. Typical crossing aircraft would issue about three position reports to Oakland radio. If a rough approximation is made that almost all messages are position reports, there would be about 100 aircraft handled per day.

4.3 Honolulu Communications

Figure 14 and Table 12 describe the ARINC owned facility in Honolulu. As with ARINC in Oakland, the CEP is served primarily by two operators on a given shift. For the most part these operators pick up communications from the same aircraft handled by Oakland.

Honolulu invoiced the FAA for 149,732 messages (of which 21,500 were estimated to be VHF) for a total cost of US$ 631,869 for the calendar year 1978. The difference between message levels at Oakland and Honolulu is attributed to South Pacific and West Pacific traffic (not included in this study). Presumably, Oakland and Honolulu would have approximately the same message loading. Hence, probably about 106,000 of the above 149,732 would represent the CEP.

4.4 CEP AFTN and ATS

The CEP AFTN and ATS direct speech circuits primarily is a U.S. domestic operation. The interface of this system with areas to the west and south (i.e., Asia, the South Pacific, and parts of Western Latin America) has not been described in this study. No major voice or data communication flaws were found within this area.

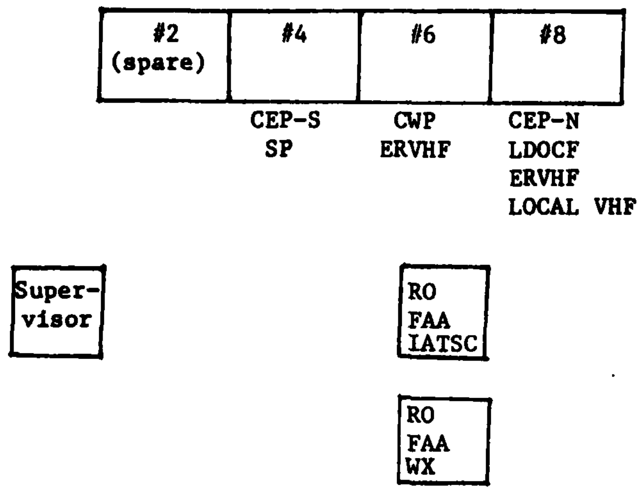


FIGURE 14 HONOLULU ARINC COMMUNICATIONS CENTER AT HONOLULU AIRPORT

Table 12

HONOLULU ARINC COMMUNICATIONS CENTER
TECHNICAL SUMMARY

HF EQUIPMENT

Aeronautical Mobile Transmitters

Number and Type: 5 Aerocom Model 1330 5 kW transmitters for LDOCF, CEP-5-N, CWP, SP, CEP-5-S families.

Antenna: An omnidirectional TCI model 530LP with 6 DB gain is used for LDOCF. CEP-5-N uses a Rhombic with 14 degree beam and 12 DB gain pointed at 38 degrees. CWP uses a VOR with 20 degree beamwidth and 7 DB gain pointed at 275 degrees. SP uses a Vee-like CWP pointed at 205 degrees. CEP-5-S uses a rhombic with 14 degree beamwidth and 12 DB gain pointed at 39 degrees. All on Molokai.

Characteristics: See Table 12.

Backups: Aerocom 1 kW 1311 with whip for LDOCF and Dipoles at Honolulu Communications Center.

Aeronautical Receivers

Number and Type: 26 Kahn RBI-A1.

Antenna: All TCI model 530LP omnidirectional on Molokai.

Characteristics: See Table 12.

Backups: McKay-Dymek DR-33C tunable at Honolulu.

VHF EQUIPMENT

Transceivers and location: Extended range on Mt. Haleakala (Maui) pointed at 54 degrees and regular VHF at Molokai. Operates on 131.94 MHz.

Communications to other facilities: telephones direct to oceanic ATC positions. Also, ESS connection to AFTN.

5.0 THE CAR

5.1 Introduction

The two major communication stations serving the CAR from the United States are San Juan and New York. New York has been described in the NAT section but some additional information is given here relative to its current handling of the CAR traffic. The New York facility can serve both the Houston, Texas and the Miami, Florida ATC centers.

The area of the CAR considered in this study includes several FIRs which can conduct most communications with VHF. The Merida, Havana, Curacao, Santa Domingo, Port-Au-Prince, Kingston, Maiquetia, San Juan, and Miami FIRs have land sites which could (in theory) be used for remote VHF transmitter sites. These sites would cover most of their high altitude aircraft movements and some low flying aircraft. Certain Gulf of Mexico tracks which are of sufficiently high altitude have been approved for VHF (only) operation (i.e. HF not required) . In practice, the geography and remoteness of many areas make installation of remote sites economically difficult for provider states.

The FIRs in which HF is a critical factor include San Juan and Piarco which service extensive oceanic airspace. Piarco communications charges are actually paid to International Aeradio (Caribbean) Ltd., rather than to the Trinidad and Tobago government which is responsible for this FIR.

5.2 San Juan Communications Station

Table 13 and Figure 15 depict the relatively small San Juan communications station. This center primarily handles communications from offshore traffic proceeding parallel to the U.S. coastline between the New York FIR and CAR FIRs. There is also a limited amount of trans oceanic traffic (CAR toward Europe) with which it communicates. Generally two radio operators can handle the HF load.

In 1978 San Juan billed the FAA for 79,053 HF transactions at a cost of US$ 333,603. During the days of NAT message analysis (ref. 5) San Juan averaged 85 position reports per day on the NAT frequencies.

This would suggest that approximately 31,025 (85 x 365) of San Juan's messages are on NAT frequencies. It is not known whether this is primarily from New York, San Juan, or other FIR traffic. Perhaps aircraft in the San Juan or Miami FIRs simply retain NAT frequencies as they often transition into NAT FIRs.

Table 13

SAN JUAN ARINC COMMUNICATIONS STATION

HF EQUIPMENT

Aeronautical Mobile Transmitters

Number and Type: 3 Aerocom Model 1330 5 kW dedicated to NAT-A, ECAR and Long Distance Operational Control (LDOCF).

Antenna: At Carolina, Puerto Rico, each transmitter has TCI model 613 omnidirectional antenna with 5 DBI gain.

Characteristics: See Table 11.

Backups: 3 1 kW Aerocom 1311 transmitters with omnidirectional dipoles.

Aeronautical Receivers: 16 KAHN RBI-A1 for 5 NAT-A, 6 ECAR and 5 LDOCF frequencies.

Antenna: TCI model 613 omnidirectional at Carolina, Puerto Rico.

Characteristics: See Table 11.

Backups: Tunable McKay-Dymek DR-33C.

VHF EQUIPMENT

Transceivers and location: 1 VHF site on El Yanque Mountain in Puerto Rico--130.4 MHz.

Communications to other facilities: direct telephone for all communications to ATC in San Juan.

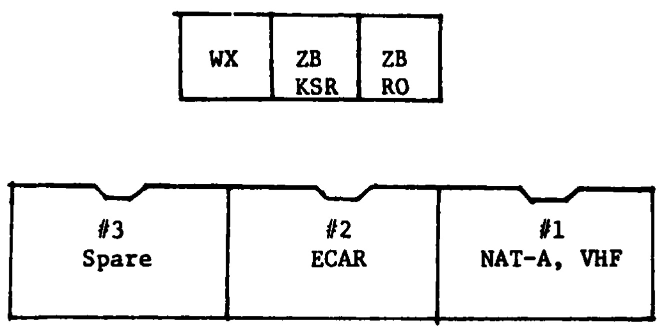


FIGURE 15 SAN JUAN ARINC COMMUNICATIONS CENTER

The CAR does not exhibit the same degree of organization with respect to networking communications as does the NAT. There do not appear to be agreements on message intercepts between San Juan, Piarco, etc.

5.3 New York Communications Station

Detailed data on this station was provided in Section 3.0. New York has recently assumed coverage of the West CAR using its ERVHF facilities operated remotely from New York and HF antennas located on Long Island. Charges to the FAA for the Miami station amounted to US $182,350 in 1978 for 43,211 messages. Of these about 12,100 were estimated to have been transmitted on VHF. The FAA is currently implementing additional ERVHF in such areas as Brownsville, Texas, to accommodate more of the CAR; however, discussions with Houston controllers indicated there were no plans for coverage of coastal areas now serviced by ARINC VHF.

5.4 Merida Communications Station

The Merida station operates a VHF frequency on 126.9 MHz and the HF frequencies 2966, 5568, 10017 and 13320 KHz. This station is operated by the Mexican Air Space Navigation Services (SENEAM) under the Office of the Secretary for Communication and Transport. There are seven radio operators, 40 technicians and 10 administrative personnel in this station who transmit data to other facilities via AFTN. At present there is little technical data available on this station. Apparently, part of its function is to serve the three service areas of Mexico, Mazatlan, and Monterrey as well as the Merida, FIR.

Merida ATC has one approach control and three en route VHF frequencies (121.2, 125.8, 121.5, 128.2 MHz) available for direct pilot-controller communications with aircraft arriving from areas considered in this project. The extent of this coverage is not known. In particular, the degree to which the communications station must supplement direct pilot-controller communications via HF is unknown.

5.5 Port-Au-Prince

This FIR uses VHF and ERVHF communications only. The six major airports all have their VHF facilities on site. Communications are the responsibility of the Administration de l'Aeroport International Francois Duvalier and Direction General de l'Aviation Civile.

5.6 Other CAR Communication Facilities

At this writing, data on communication facilities in areas such as Havanna, Maiquetia, etc. was limited to that contained ICAO literature and documents used to supply operating data to carriers (e.g., navigation charts). Most enroute communications in these areas are believed to be handled by personnel operating in flight service stations. In the

case of long range oceanic communications requiring HF, available charts show Radio Nassau with four frequencies in the E-CAR, Boyeros radio providing service on this same family monitoring 5484 KHz continually, 2952 KHz at night and 6540 and 8959 KHz in the day.

Piarco radio (International Airadio Caribbean Limited) is shown as monitoring 2952, 5484, 6540, 8959, 11367 and 17925 KHz continuously without SELCAL and Maiquetio radio is shown monitoring 2952, 5484, 6540, 8959, 11343, and 13320 KHz continuously with SELCAL. Curacao is shown as continuously monitoring 8959 KHz plus 5484 during dayflight with SELCAL. The Santa Domingo FIR is shown as having Caucedo radio monitoring 2952, 6540 and 8959 KHz continuously (without SELCAL).

Comments from air carriers using the CAR indicate that they believe better VHF coverage could be provided in the CAR by locating and monitoring VHF frequencies in a suitable manner. Additional analysis of resources and constraints in various portions of the CAR must be made in order to objectively assess the present system and make recommendations on possible CAR communication improvement options.

5.7 CAR AFTN

Most of the points considered in this study were interfaced to the Kansas City switching center via outlets at various U.S. terminals. For example, a link between Cuba and Miami terminals of the AFTN is provided by common carrier. There are similar connections to San Juan, Santa Domingo, Kingston, etc.

The CAR AFTN appears much weaker than the NAT network. Only incomplete data currently is available for the CAR but there seem to be two sources of difficulty with CAR AFTN. First, many nations in the CAR have less reliable telephone service than that in the NAT and CEP regions. Secondly, the input mechanics (as constrained by hardware, personnel, or political considerations) for generating AFTN message flows are not well developed.

It is particularly important in the CAR to have reliable, timely communications between the many authorities operating in such a relatively small area. The lack of radar coverage in this area coupled with limited AFTN and other factors may make parts of the CAR less safe operationally than the NAT.

The AFTN in the CAR is used less for handing off aircraft from one control facility to another than in the NAT. Merida, for example, has indicated that its handoffs are all via voice circuits.

5.8 CAR ATS

The CAR ATS direct speech network uses numerous switched lines to effect voice communications between air traffic controllers. In the CAR ATC, handoffs are handled by speech circuits rather than by the AFTN. This is partially due to the quality of the AFTN and in part due to

procedural preferences. Direct observation was made of several ATS links. Houston to Merida (via a voice request to Mexico) proved to have fairly noisy voice communications. A line from San Juan to Maiquetia apparently had a single-ring signal at the Maiquetia end, thereby increasing the probability of not getting answered. Houston communicated with Havana and other places through a single shared-line through Miami. In general, it appears that the entire CAR would benefit from the implementation of a well-designed switching network for voice to improve the quality and accessibility of controller-to-controller communications.

Most ATS lines in the area studied are in submarine cables or land lines. Some links, such as Merida to Havana, are via very unreliable HF radio.

6.0 COMMUNICATIONS FINANCIAL INFORMATION

6.1 Overview of User Charges

Provision of oceanic communications imposes costs associated with:

(1) Ground facilities that can support air-to-ground contact, including labor that is dedicated to maintaining communications equipment and labor which is dedicated to actually carry out communications.

(2) Various point-to-point communication channels connecting facilities (lines are usually leased from common carriers).

(3) Procurement and maintenance of airborne equipment consisting primarily of dual HF transceivers and antennas (all aircraft are equipped with VHF transceivers for domestic use).

Data on costs of these elements were estimated from technical descriptions of the systems, charges for the system to users, and some specific references (e.g., ref. 12, 13, 14) on facility financing. Information on user charges were obtained from the International Air Transport Association (IATA).

Before thoroughly examining communications costs it is useful to explore some oceanic operating costs so that communications and ATC charges can be put in perspective. For this purpose we look principally at the NAT. A typical 747 aircraft flying the NAT between a North American and European destination experiences some of the approximate costs shown in Table 14. Of the US$ 200 oceanic services fee, approximately US$ 100 is communications oriented. In the "other flight equipment" category of direct maintenance and the "nondirect cost" section, some depreciation, etc., is involved in HF radios. Assuming an aircraft value of $50,000,000, a dual HF installation of US$ 50,000 and an approximately linear relation between indirect costs, about US .60/hr would be attributed to the costs for HF installations. Table 15 estimates costs attributable to oceanic air-to-ground communications. Note that these costs are approximately 0.3 percent of the total trip cost. Changes to the communications system which might slightly improve operating efficiency (e.g., on the order of 1 percent) of flight times or by slight changes in fuel consumption via better track assignment certainly would be of major interest to that community.

Table 14

TYPICAL OPERATING COSTS ASSOCIATED WITH A SEVEN-HOUR 747 NAT FLIGHT

	Cost for Seven-Hour Flight
Flight operations	
Crew costs (647/hr)	$ 4529
Fuel and Oil (1808/hr)	12656
Insurance (4/hr)	28
Taxes (32/hr)	224
Other (4/hr)	28
Total	17465
Direct maintenance	
Airframes (193/hr)	1351
Engines (277/hr)	1939
Other flight equipment (57.29/hr)	401
Total	3691
Indirect costs	
Depreciation (350/hr)	3000
Amortization (141/hr)	987
Rentals (31/hr)	217
Maintenance burden (402/hr)	2814
Total	6468
Estimates of costs for passenger Aircraft (cabin crew, food, etc.)	
Crew (650/hr)	4550
Food	3000
Total	7550
Total trip cost	37979
Terminal charges	2500
Eurocontrol charges (function of countries)	100
Combined oceanic ATC and communication charges	200

*Hourly operating costs were obtained from Aviation Daily, Oct. 24, 1979.

Table 15

AN ESTIMATE OF SPECIAL OCEANIC COMMUNICATION COSTS FOR SEVEN-HOUR NAT FLIGHT
(In U.S. Dollars)

Direct maintenance to HF radios (2/hr)	$14
Nondirect costs (1 hr)	7
Provider charges	50
Total	71

6.2 Financial Data Communication Estimates by Region and by Facility

In this discussion communication system costs were estimated by region and by facility. Emphasis is given to broad categories of cost such as labor and equipment. Where facility data for an item was not available at this writing, figures have been extrapolated from known facility parameters such as number of frequencies operated and number of position reports copied. Cost data for CAR is very incomplete due to the myriad of small FIRs involved and lack of hard data concerning CAR operations and facilities. Costs were based on 1978 figures and exchange rates were based on the 1978 final quarter average.

Some facilities such as those associated with New York, San Juan, and Honolulu span more than one of the three regions (CAR, CEP, NAT) considered in the project. Therefore, arbitrary cost allocations have been made to each region.

6.2.1 NAT Communications Financial Information

Table 16 presents estimates of communication costs for the NAT. The three categories labeled "labor," "nonlabor," and "indirect" costs actually deal with communication facility costs, whereas the leased lines costs are usually (but not always) associated with ATC facility costs. All costs are rough estimates except Reykjavik's for which extensive accounting is required by ICAO agreement. For Gander, source data provided only aggregated cost estimates with limited explanations of category definition (ref. 15). In the case of Shannon, data provided only a gross revenue figure which was assumed to equal cost (ref. 16) Given the limitations of available data, it is surmised that individual costs are accurate to within plus or minus 20 percent of actual value.

6.2.2 CEP Communications Financial Information

CEP costs were estimated for the two ARINC facilities in this region and the leased lines used by the FAA to transmit voice and AFTN data. Honolulu ARINC provides additional services for other Pacific regions which are not included in the cost estimates. Table 17 summarizes the costs.

There is a need to coordinate oceanic traffic from several non-CEP areas with traffic entering the CEP FIRs. Costs for those lines were not included, but Oakland, California, personnel and others have expressed desire for additional communication lines linking such areas as the South Pacific with Oakland.

6.2.3 CAR Communications Financial Information

Extremely limited data was available from the CAR providers. Based on informal discussions with the aviation community and the data received to date (ref. 18, 19, 20), most CAR areas provide essentially domestic VHF communication services. No data was available for Piarco FIR (operated by Trinidad and Tobago), Maiquetia (operated by

Table 16

NAT FINANCIAL ESTIMATES FOR PROVIDER COMMUNICATION FACILITIES
(EXCLUDING ATC PILOT/CONTROLLER VHF COMMUNICATIONS) $US FOR YEAR 1979

	Gander	Shanwick(2)	Gufunes	Santa Maria(5)	New York(4)	San Juan	Total
Labor (Radio operators, etc.) and administration	1,782,464	1,535,175	1,006,462	688,000	641,164	278,524	5,881,789
Direct operating costs	535,217	461,360	302,208	192,500	192,687	83,703	1,767,675
Indirect costs	28,762	24,271	16,241	9,900	10,136	4,400	93,710
Leased lines (AFTN and AFS)	852,126(1)	99,776(3)	409,864	237,600	237,600	211,200	2,048,166
Total	3,198,569	2,120,582	1,734,775	1,078,000	1,081,587	577,827	9,791,340

Labor: Includes radio operator, maintenance personnel, administrative overhead. Indirect costs do not include administration but do include interest, depreciation etc. Direct operating costs include maintenance parts, power, etc. leasing local telephone services.

(1) About $324,495 is ATS circuits, includes ADIS Gander-Montreal circuits.

(2) No detailed cost data was available for this center. However, total revenue figures of 1,838,754 was given in reference 5 for the year 1978.

(3) From ref. 6 - UK rents cables.

(4) Total billings to the FAA were apportioned based on relationships observed at other facilities. Leased lines estimated.

(5) Estimates based on the fact that New York and Santa Maria do roughly the same volume of communications. New York costs were used.

(6) Most hard financial data available at this writing was applicable to 1978. A ten percent inflation factor was added to extrapolate 1978 figures.

Table 17

CEP 1979 FINANCIAL ESTIMATES FOR
PROVIDER COMMUNICATION FACILITIES
(In U.S. Dollars)

	OAKLAND	HONOLULU(2)
Labor	376,031	376,031
Nonlabor Operating	113,007	113,007
Indirect	5,500	5,500
Leased Lines	105,600(1)	105,600(1)

(1) Estimate of lines for SF/Honolulu.

(2) Honolulu assumed same as Oakland for CEP--excluded estimated portion of costs for Eastern Pacific areas.

(3) Estimated from 1978 data using 10 percent yearly inflation function.

Venezuela), Curacao (operated by the Netherlands Antilles), Havana, etc. The San Juan and New York radio centers which cover the CAR incur approximately equal costs as the NAT, as shown in Table 16.

6.3 System Cost Elements

Some specific items required to operate oceanic communications are delineated in this discussion. Items are estimated from contacts with equipment manufacturers, lessors of services, and provider nations. Some costs, such as labor, can vary greatly from area to area and hence are only rough estimates.

Table 18 summarizes cost elements associated with oceanic systems. One cost element sometimes overlooked is the collecting of AFTN messages, and switching and distributing them domestically in highly-developed areas where AFTN data are simply merged into the domestic system. For Canada and the UK, lines linking oceanic facilities to central computers are explicitly charged against oceanic operations (although the degree, if any, of domestic information they might carry is unknown).

In the current system labor elements dominate costs. Equipment involved can have a useful lifetime of 20 years or more and can require relatively little maintenance.

Various communication line costs (e.g., items 2 and 7 in Table 18) may be somewhat arbitrary because lines are often purchased from government institutions that may choose to charge more or less for a line than its actual cost. Aviation and other communities occasionally operate their own point-to-point HF long-distance communications which are less reliable and more cumbersome than ordinary lines; however, they may be considerably less expensive than purchasing common carrier lines. Communication line costs are generally minimized by (1) sharing a line by sending data and voice over a line simultaneously, and (2) using switching to allow linkups via intermediate facilities such as the use of the Gander/New York/Santa Maria lines to permit Gander/Santa Maria communications.

6.4 User Charges

Table 19 contains a summary of all user charges relevant to the NAT, CEP and CAR (ref. 18). In some cases the charges imposed (if any) are not known. Where complicated formulas were used to calculate the charges for a particular flight, a typical 500,000 lb aircraft flying 1,000 km was used to derive an example figure. Note that there is a variety of charge information associated with the CAR. Typically, there is a total charge for overflight and no specific demarcation exists between ATC and communication services. Apparently, most of those charges are for nondirectional beacon (NDB) operation and terminal VHF stations manned by flight service station personnel, although the Piarco FIR, which is served by International Aeradio (Caribbean) Ltd., may operate an HF facility simil[illegible] to San Juan ARINC.

Table 18

Communication Cost Elements

Cost Element	Comments
(1) Labor to continuously man radio positions and relay data via teletype or telephone to ATC or other facilities and perform maintenance and managerial functions.	Minimal number of radio operators for a station is normally 2 to provide redundancy. Busy stations appear to need at least 1 operator for each 12 position reports issued in an hour. In addition 1 VOLMET person, 1 supervisor and two or more teletype operators are required in big stations.
(2) Lease of communications lines to provide ATC voice between adjacent centers and teletype data flow (flight plans, met, etc.) between relevant facilities.	International circuits between countries (voice grade) are paid for by both users. U.S. costs for individual voice grade lines to Europe, Caribbean and Honolulu from private companies cost approximately $4,000 per month which tends to be the minimum rate costs (for the other half lines vary from $4,000 to $12,000 per month from government providers).
(3) Transmitters and receiver sites and ancillary equipment including antenna for both VHF and HF air-to-ground communications.	HF transmitters capable of single sideband remote operation with radiated power of 1 to 5 KW cost approximately $50,000. Receivers cost considerably less. Antennas, etc. are estimated at $10,000 each, receivers at $5,000 each. A single frequency dual remote conventional VHF system with antenna is estimated to cost $20,000 - $40,000
(4) Housing for personnel and equipment sites for antennas and transmitters.	Less than 10 sq. meters of space per communication position person is required to house operators and equipment. Antenna sites require large, secure, uncluttered areas, generally several hundreds of meters in either direction and are generally many kilometers from the radio operators' housing.
(5) Miscellaneous support equipment such as teletypes, CRT's, message buffering and switching equipment.	Typical costs of CRT's, low speed printer, etc. is currently on the order of $3,000 per unit. Switching equipment has not been explicitly costed but a sophisticated redundant computer installation with software and interface equipment is estimated to cost under $100,000.
(6) Aircraft equipment.	VHF equipment is carried on all transports for terminal areas. HF radios which are used primarily for oceanic and undeveloped areas generally cost $40,000 for a dual installation. Maintenance costs have been estimated at one to several dollars per flight hour.
(7) Remoting lines for VHF, HF transceiver sites and for communications between facilities such as radio centers and ATC centers.	Monthly costs can range from a hundred dollars to several thousand dollars for voice grade lines depending on country and length.

Table 19

USER CHARGES BY FIR

FIR	User Charges (1979 US Dollars)
Gander	$72 ($27 for communication, $45 other items)
Shannon Reykjavik	$72 for UK, $18 for Ireland, $38 for Denmark and Iceland.
New York	*
Miami	*
San Juan	*
Santa Maria	Not known--if Eurocontrol rates apply would be $240 for 500,000 lb aircraft on 1,000 km flight
Piarco	$23 (20.83 communications, 2.21 for NDB use)
Maiquetia	Tabular function used on weight and distance $293 for 500,000 lb aircraft on 500-1,000 km overflight
Curacao (Netherlands Antilles)	Not known
Santa Domingo	$15 per flight
Merida	Weight dependent charge for Mexico overflight $51.51 for a 500,000 lb aircraft
Houston	*
Habana	$30 per overflight ($25 if not flying over land)
Haiti	$3.50 per hour radio watch, $1.50 per radio message; meteorological forecast $5.00
Kingston	$7.26 per flight
Honolulu	*
Oakland	*

*Cost recovered by other means.

Appendix A

Excerpts from ICAO Annex 10

Relevant to Aeronautical Mobile Communications

4.8.—SELCAL System

4.8.1 RECOMMENDATION.— *Where a SELCAL system is installed, the following system characteristics should be applied:*

a) Transmitted code. *Each transmitted code should be made up of two consecutive tone pulses, with each pulse containing two simultaneously transmitted tones. The pulses should be of 1.0 plus or minus 0.25 seconds duration, separated by an interval of 0.2 plus or minus 0.1 second.*

b) Stability. *The frequency of transmitted tones should be held to plus or minus 0.15 per cent tolerance to ensure proper operation of the airborne decoder.*

c) Distortion. *The overall audio distorsion present on the transmitted r-f signal should not exceed 15 per cent.*

d) Per cent modulation. *The r-f signal transmitted by the ground radio station should contain, within 3 dB, equal amounts of the two modulating tones. The combination of tones should result in a modulation envelope having a nominal modulation percentage as high as possible and in no case less than 60 per cent.*

e) Transmitted tones. *Tone codes should be made up of various combinations of the tones listed in the following table and designated by colour and letter as indicated:*

TABLE OF TONE FREQUENCIES

Designation	*Frequency (Hz)*
Red A	312.6
Red B	346.7
Red C	384.6
Red D	426.6
Red E	473.2
Red F	524.8
Red G	582.1
Red H	645.7
Red J	716.1
Red K	794.3
Red L	881.0
Red M	977.2
Blue A	323.6
Blue B	358.9
Blue C	398.1
Blue D	441.6
Blue E	489.8
Blue F	543.3
Blue G	602.6
Blue H	668.3
Blue J	741.3
Blue K	822.2
Blue L	912.0
Blue M	1 011.6
Yellow A	335.0
Yellow B	371.5
Yellow C	412.1
Yellow D	457.1
Yellow E	507.0
Yellow F	562.3
Yellow G	623.7
Yellow H	691.8
Yellow J	767.4
Yellow K	851.1
Yellow L	944.1
Yellow M	1.047.1

Note 1.—It should be noted that the tones in any one colour group are spaced by Log-1 *0.045 to avoid the possibility of harmonic combinations.*

Note 2.—In accordance with the application principles developed by the Sixth Session of the Communications Division, the only codes at present used internationally are selected from the red group.

Note 3.—Guidance material on the use of SELCAL systems is contained in Attachment D to Part I.

4.11.—Single Side-Band (SSB) HF Radiotelephone Communication System Characteristics for Use in the Aeronautical Mobile Service

4.11.1 The characteristics of the air-ground HF SSB system, where used in the Aeronautical Mobile Service, shall be in conformity with the following specification:

4.11.1.1 *Frequency range.*

4.11.1.1.1 HF SSB installations shall be capable of operation at any SSB reference frequency available to the Aeronautical Mobile (R) Service in the band 2 MHz to 22 MHz and necessary to meet the approved assignment plan for the Region(s) in which the system is intended to operate, and in compliance with the relevant provisions of the ITU Radio Regulations.

Note 1.—See Introduction to Chapter 3, Part II and Fig. 4-1.

Note 2.—The Extraordinary Administrative Radio-Conference (EARC), Geneva, 1966, established a new Allotment Plan (Appendix 27 to the ITU Radio Regulations) which provides for the following channel utilization:

3.4 *Channel utilization.*

27/67 3.4.1 A station using single side-band emissions shall be considered to be operating in accordance with the Allotment Plan if the necessary bandwidth is confined within either the upper or the lower half of the channel provided for double side-band emissions;

27/68 3.4.2 Subject to the provisions of No. 27/12* and to the following conditions, a station using single side-band emissions may operate either in the upper half or in the lower half of a double side-band channel designated by its centre frequency in the Allotment Plan;

27/69 *a*) when operating in the upper half of the channel, the station shall use upper side-band emissions with the carrier at the channel centre frequency listed in the Allotment Plan;

27/70 *b*) equipment capable of operating only on integral multiples of 1 kHz shall be restricted to the upper halves of the channels listed in the Allotment Plan, when operated in channels having a width of 7 kHz;

27/71 *c*) when operating in the lower half of the channel, the station shall use upper side-band emissions with the carrier at the following value below the channel centre frequency listed in the Allotment Plan:

Band	*Carrier (reference) frequency relative to centre frequency of channel*
2, 3, 4, 5, 6 and 8 MHz	3 500 Hz below
10, 11, 13 and 17 MHz	4 000 Hz below

Note 3.—It is recognized that Regions may assign the lower half of the channels allowed by the ITU Allotment Plan (Appendix 27 to the ITU Radio Regulations). Accordingly, ground and airborne installations operating in such a Region would be required to have 500 Hz channelling capability below 10 MHz. However, those ground and airborne installations which had no requirement to operate in such a Region, or no requirement to operate below 10 MHz, would require only a 1 000 Hz channelling capability.

Note 4.—It is also recognized that, during the currency of the HF Allotment Plan contained in Appendix 26 to the ITU Radio Regulations, and pending the bringing into force of the revised Plan contained in Appendix 27, equipment having only a 1 000 Hz channelling capability may operate on frequencies 0.5 kHz below the channel frequencies when these end in half kilohertz.

* Provision 27/12 stipulates that the use of channels for the various authorized classes of emission will be subject to specific arrangements by the Administrations concerned.

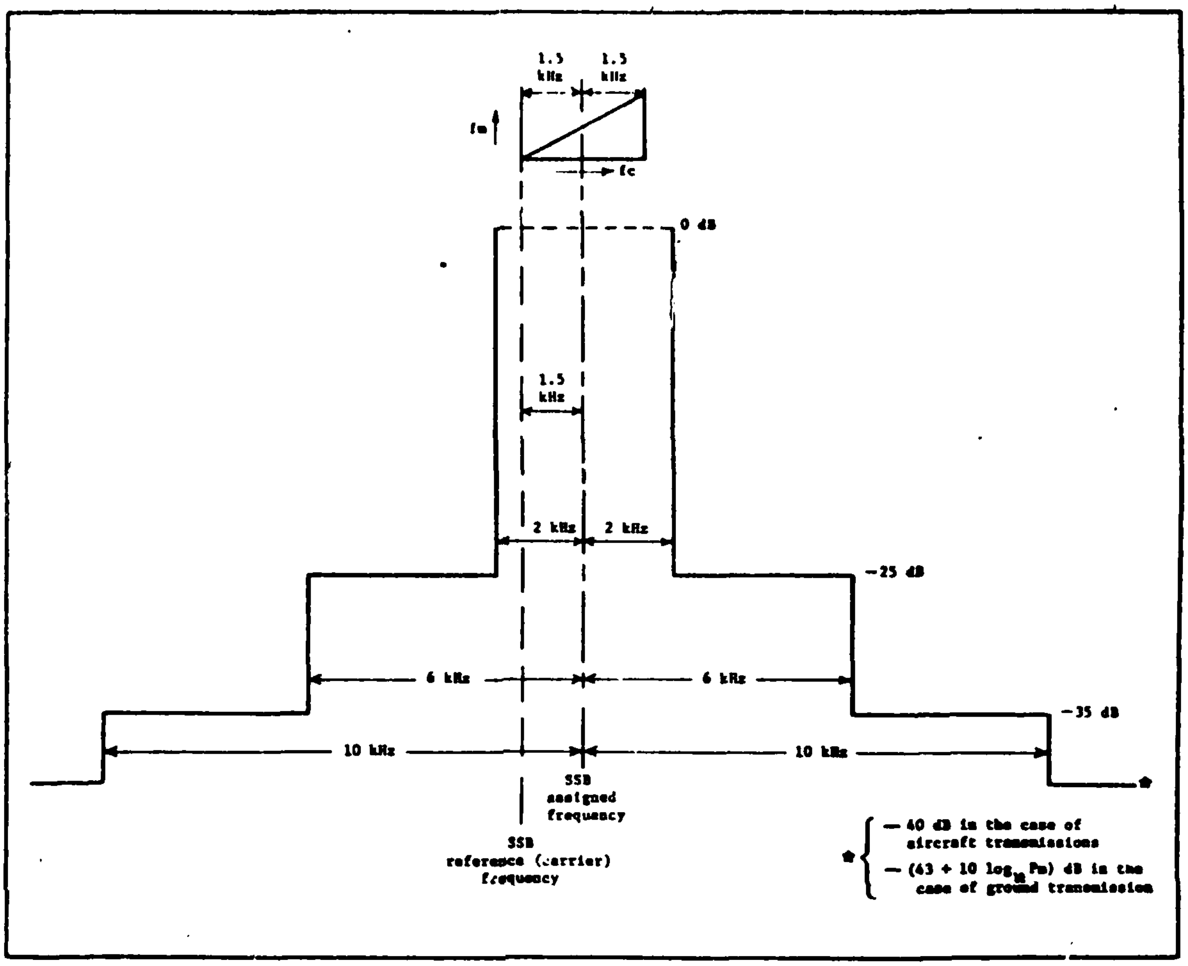


Fig. 4-1. — Required side-band attenuation characteristic

4.11.1.2 *Side-band selection.*

4.11.1.2.1 The side-band transmitted shall be that on the higher frequency side of its reference frequency.

4.11.1.3 *Reference frequency.*

4.11.1.3.1 The SSB reference frequency:

a) in the higher frequency half of a DSB channel, shall be that of the DSB carrier;

b) in the lower frequency half of a DSB channel, shall be:

i) 3.5 kHz lower than the DSB carrier where the latter are spaced at 7 kHz;

ii) 4 kHz lower than the DSB carrier where the latter are spaced at 8 kHz.

Note.—See also Attachment D to Part I.

4.11.1.4 *Carrier mode.*

4.11.1.4.1 The system shall operate in the suppressed carrier mode (A3J). Where communication is necessary with installations designed only for DSB reception, or where SELCAL is employed as specified in 4.8 of Part I, and when DSB emission is not provided, the installation shall be capable of operation in the full carrier mode (A3H) in addition to A3J.

Note.—Current ITU Radio Regulations require a minimum of 26 dB carrier suppression with respect to peak envelope power in Mode A3J.

4.11.1.4.2 **Recommendation.**—*Ground installations should be capable of 40 dB carrier suppression with respect to peak envelope power.*

4.11.1.5 *Frequency tolerance.*

4.11.1.5.1 The basic frequency stability of the transmitting function in the A3J mode shall be such that the

Appendix B

Excerpts from Appendix 27 of the ITU

Table of Frequency Tolerances	**- Aeronautical Stations**	**10Hz**
	- Aircraft Stations	**20Hz**
	Aircraft operating exclusively on national allocations	**50Hz**

Channel Characteristics - **3KHz with Carrier Reference frequency on integral multiples of 1KHz in band 2850 - 17970 (and in 21MHz band also - not part of MOD APP 27)**

Copy of pages 11, 12, 13, 14, and 15 of the World Administration Radio Conference on the Aeronautical Mobile (R) Service Geneva 1978, Annex 2 attached.

NOC C. Classes of emission and power

NOC 1. Classes of emission

MOD 27/49 In the aeronautical mobile (R) service the use of emissions such as those listed below is permissible subject to compliance with the special provisions applicable to each case and provided that such use does not cause harmful interference to other users of the channel concerned.

MOD 27/50 1.1 Telephony – Amplitude modulation:

- double sideband (A3) *
- single sideband, full carrier (A3H) *
- single sideband, suppressed carrier (A3J)

* A3 and A3H to be used only on 3023 kHz and 5680 kHz as well as in cases covered by Resolution Aer2 – E, resolves 5.

NOC 1.2 Telegraphy (including automatic data transmission)

MOD 27/51 1.2.1 Amplitude modulation:

- telegraphy without the use of a modulating audio frequency (by on-off keying)

- telegraphy by the on-off keying of an amplitude modulating audio frequency or audio frequencies or by the on-off keying of the modulated emission and including selective calling, single sideband, full carrier (A2H)

- multichannel voice frequency telegraphy, single sideband, suppressed carrier (A7J)

- other transmission such as automatic data transmission, single sideband, suppressed carrier (A9J)

MOD 27/52 1.2.2 Frequency modulation

- telegraphy by frequency shift keying without the use of a modulating audio frequency, one of two frequencies being emitted at any instant (F1) **

** A1 and F1 are permitted provided they do not cause harmful interference to the classes of emission A2H, A3J, A7J and A9J. In addition, A1 and F1 emissions shall be in accordance with the provisions in 27/65 to 27/66B and care should be taken to place these emissions at or near the centre of the channel. However, a modulating audio frequency is permitted with single sideband transmitters, where the carrier is supressed in accordance with No. 27/63.

SUP 27/53

NOC 2. Power

MOD 27/54 2.1 Unless otherwise specified in Part II of this Appendix, the peak envelope powers supplied to the antenna transmission line shall not exceed the maximum values indicated in the table below; the corresponding peak effective radiated powers being assumed to be equal to two-thirds of these values:

Class of emission	Stations	Maximum peak envelope power
A2H, A3J, A7J, A9J A3*), A3H*) (100 % modulation)	Aeronautical stations Aircraft stations	6 kW 400 W
Other emissions such as A1, F1	Aeronautical stations Aircraft stations	1.5 kW 100 W

*) A3 and A3H to be used only on 3 023 kHz and 5 680 kHz, as well as in cases covered by Resolution Aer2 - E, resolves 5.

MOD 27/55 2.2 It is assumed that the maximum peak envelope powers specified above for aeronautical stations will produce the mean effective radiated power of 1 kW used as a basis for the interference range contours.

MOD 27/56 2.3 In order to provide satisfactory communication with aircraft, aeronautical stations serving MWARA, VOLMET [and world-wide areas] may exceed the power limits specified in No. 27/54. Except in the case of 3023 kHz and 5680 kHz which are subject to special provisions [Nos. 27/196 and 27/201]. In each such case, the administration having jurisdiction over the aeronautical station shall note No. 694 of the Radio Regulations and ensure:

NOC 27/57

NOC 27/58

NOC 27/59

NOC 27/60

NOC 27/61

MOD 27/62 2.4 It is recognized that the power employed by aircraft transmitters may, in practice, exceed the limits specified in No. 27/54. However, the use of such increased power (which normally should not exceed 600 W Pp) shall not cause harmful interference to stations using frequencies in accordance with the technical principles on which the Allotment Plan is based.

ADD D. **Limits to the power levels of unwanted emissions**

MOD 1. Technical provisions relating to the use of single-sideband emissions.

MOD 27/63 1.1 Definitions of carrier modes:

Carrier mode	Level N (dB) of the carrier with respect to peak envelope power
Full carrier (for example A2H)	$0 \geq N \geq -6$
Suppressed carrier (for example A3J)	Aircraft stations $N < -26$ Aeronautical stations $N < -40$

SUP 27/64

MOD 2. Tolerance for levels of emission outside the necessary bandwidth.

MOD 27/65 2.1 In a single-sideband transmission, the mean power of any emission supplied to the antenna transmission line of an aeronautical or aircraft station on any discrete frequency, shall be less than the mean power (Pm) of the transmitter in accordance with the following table:

MOD 27/66 2.2 For aircraft station transmitter types and for aeronautical station transmitters first installed before 1 February 1983:

Frequency separation Δ from the assigned frequency kHz	Minimum attenuation below mean power (Pm) dB
$2 \leq \Delta < 6$	25
$6 \leq \Delta < 10$	35
$10 \leq \Delta$	Aircraft stations 40 Aeronautical stations $43 + 10 \log_{10}$ Pm (watts)

Note. — All transmitters first placed in operation after 1 February 1983 shall comply with the specifications contained in 27/66B.

ADD 27/66A 2.3 In a single-sideband transmission, the peak envelope power (Pp) of any emission supplied to the antenna transmission line of an aeronautical or aircraft station on any discrete frequency, shall be less than the peak envelope power (Pp) of the transmitter in accordance with the following table.

ADD 27/66B 2.4 For aircraft station transmitters first installed after 1 February 1983 and for aeronautical station transmitters in use after 1 February 1983.

Frequency separation Δ from the assigned frequency kHz	Minimum attenuation below peak envelope power (Pp) dB
$1.5 \leq \Delta < 4.5$	30
$4.5 \leq \Delta < 7.5$	38
$7.5 \leq \Delta$	Aircraft stations 43 Aeronautical stations *)

*) For transmitter powers up to and including 50 watts
$43 + 10 \log_{10} Pp$ (watts)

For transmitter powers more than 50 watts, the attenuation shall be at least 60 dB.

SUP 27/67 to 27/71

ADD **E. Other technical provisions**

MOD 1. Assigned frequencies

MOD 27/72 1.1 For single-sideband emissions, except class of emission A2H, the assigned frequency shall be at a value 1400 Hz above the carrier (reference) frequency.

ADD 27/72A 1.2 For aeronautical stations equipped with selective calling systems, the class of emission A2H shall be indicated in the Supplementary Information column of the Form of Notice (see Appendix 1 to the Radio Regulations).

ADD 27/72B 1.3 For classes of emission A1 and F1 the assigned frequency shall be chosen in accordance with the provisions of the footnote to 27/51 and 27/52.

MOD 27/73 1.4 Stations employing double-sideband emissions (A3) shall operate with an assigned frequency at 3023 kHz or 5680 kHz (see 27/50).

APPENDIX C

HF Communications Background

Material in this appendix is directly abstracted from a document prepared by Mr. G. W. (Bill) Irvine representing Canada in Working Group B meetings. The material presented here serves as a particularly well written introduction to technical issues involved in HF communications.

Some Aspects of HF Communications

Introduction

This material is presented in support of a better understanding of the causes of high frequency communications problems and possible means of improvement. It is not exhaustive. It is a relatively qualitative look at:

- Some principles of HF Propagation.
- Some consequences for HF Communications.
- Some means of dealing with the problems.
- Some means of determining the status of HF conditions.
- What can be expected from a well designed system.

Characteristics of HF Propagation

HF can be propagated by:

- Surface Wave or
- Sky Wave.

Surface wave propagation distance depends upon:

- Ground conductivity
- Frequency
- Radiated Power
- Antenna vertical radiation pattern.

High power, low beam, low frequency, and high ground conductivity produce maximum range.

Surface wave is useful for short range only, because the propagation loss is too great to accommodate long range communications.

One situation, wherein an unusually long range of 700 miles was achieved, involved a 50K watt transmitter, 13dB of processing gain, an essentially 0 degrees antenna take-off angle and the best possible ground conductivity, viz., that of sea water. Seven hundred miles is greatly in excess of what is normally achieved.

Sky Wave Propagation

Sky wave propagation occurs because, in the upper atmosphere, solar radiation produces ionization of air molecules. The electron density produced varies with height. Measurements show that the electron density profile has more than one maximum. Various maxima in the ion density profile define the effective heights of the so called ionospheric layers:

- The E layer at about 115 km
- The F1 layer at about 180 km
- The F2 layer at about 300 km
- The D region below about 90 km.

The first three layers noted above are more highly ionized than the D region. The result is that the E, F1, and F2 layers reflect incident energy back to earth, while the D region absorbs energy. The D region absorbs energy via collision between electrons and neutral molecules, since the densities of neutral molecules are greater there than for the higher layers.

Whether or not energy is reflected depends upon a number of factors:

- Whether or not any energy penetrates the D region
- The angle of incidence at the reflecting layer
- The ion density at the point of incidence
- The frequency.

In general, the lower the frequency, the greater the D layer absorption. Therefore, if the frequency is too low, there will be no D region penetration and hence no reflection.

If we consider vertical incidence, the electron density will determine a critical frequency, below which energy will be reflected and above which energy will penetrate and be lost.

For non-vertical incidence, the cosine of the angle of incidence will also have a bearing on the maximum frequency for which reflection will occur.

If then, we consider a single reflecting layer, the lowest frequency of reflection is determined by the absorption in the D region, and the highest reflected frequency is determined by the electron density and the angle of incidence. The result is a "band" of frequencies that will propagate between two designated points. The signal strength is generally lowest at the lowest frequency, and increases toward the maximum frequency. However, there is a rapid falloff of signal strength just before the maximum frequency.

Unfortunately, it is not that simple. The physics shows that even for a single layer there are a number of possible different reflections, each having a slightly different propagation delay. There is a high angle mode which travels a slightly longer path than the low angle mode thereby producing a second signal on some frequencies at the point of reception. This high angle mode occurs only at the higher frequencies within the propagating band. For each of these paths there can be an "ordinary" and an "extra-ordinary" component which result from horizontally and vertically polarized waves and which has a very short differential time delay between them. There is also the possibility for the occurrence of 2 or more hops between points A&B again with high angle and low angle, etc.

Finally, as already discussed, there is more than one effective layer. So there may be single and multiple hop, high and low angle, ordinary and extraordinary reflection from the E layer, the F1 layer and the F2 layer, each reflection obeying the appropriate laws with respect to absorption, critical frequency and angle of incidence. And of course we have the ground wave signal. There are other modes as well. However, there is no need to discuss any further complexity in this paper.

The purpose of the above discussion is to point out that on some frequencies at some times, several signals can be received at a receiver as a result of a single transmitted signal. Those signals, which will of necessity interact with each other, will in general have different amplitudes and phases. However, it is possible for two or more of the signals to have the same amplitude and/or phase. It is also common to have single mode propagation.

Variations

Diurnal Variations

Since the ionosphere exists because of solar radiation, the electrons and ions will recombine when the sunlight disappears. Without going into the mechanisms, the general situation is that, at night:

- The D region disappears, thereby markedly reducing absorption and lowering the lowest frequency propagated. The reduced absorption also markedly increases the level of interference propagated from other sources.

- The E layer disappears

- The F1 and F2 layers become one

- The electron density reduces, thereby reducing critical frequency and hence reducing the maximum reflected density.

It is important to note that the transition periods at sunrise and sunset are the periods when the ionization is experiencing the greatest change.

Seasonal Variations

Again, since solar radiation is the cause of upper atmospheric ionization, it is reasonable to expect lesser electron densities in the winter than in the summer with a consequent lower band of frequencies expected to propagate during the winter.

Variations Due to Sunspot Activity

Occurrence of sunspots results in a higher electron density and hence, as expected, the usable band can increase in frequency when sunspot activity exists. This produces two components of variation:

- A long term component following the 11 year sunspot cycle.

- Occurrence of sporadic clc of ionization at E layer height (Sporadic E).

- High level absorption and hence, depending upon equipment parameters, blackout or partial blackout conditions.

Ionospheric Motions

Vertical or horizontal motions of the ionosphere can result in a time variation of ion density at a particular reflection point and hence in a variation of received signal strengths. It can also result in a doppler frequency shift of the received signal.

Some Consequences for HF Communications

The picture presented above is a complex one. It should be remembered that it is incomplete and only qualitative in nature. But what are the consequences for HF communications?

Blackout

Blackouts can be relatively short lived, can last for several days, or can be intermittent over several days. The longlived blackouts are rare. Blackout is the worst case situation since there will be no communications possible between the points affected by the high level absorption. It is important to note though that a blackout results from increased absorption, not infinite absorption. Also, there is a concurrent reduction in interference and noise. Therefore, blackout conditions are determined not only by the increased absorption but also by the effective power radiated by the transmitter and sometimes by the sensitivity of the receiver. Receivers built with relatively high noise figures can conceivably contribute to blackout conditions if receiver generated noise is greater than the level of the severely absorbed desired signal. Antenna pattern can also have an effect since that affects the power radiated in a given direction or received from a given direction.

Alternate routing is a powerful means of overcoming the effects of a blackout. When a blackout exists between points A and B there may not be a blackout between points A and C. The NAT network provides very significant potential for alternate routing as does aircraft to aircraft relay.

Effective Blackout

Whether or not there is a general blackout is irrelevant to the communicator. He is concerned only with whether there is a blackout over the circuit he is trying to use. Many situations occur wherein the frequencies assigned are blacked out while other frequencies which are not assigned (usually in a higher band) are enhanced or are usable when they would not normally be expected to be so (because, for example, of the occurrence of Sporadic E). An effective blackout is just as disastrous as a real blackout. Many could be avoided by changes in equipment design and utilization.

Poor Signal-to-Noise Ratio

One factor mentioned only briefly so far is that of noise or interference. This can vary greatly both in character and intensity. It can be man-made due to electrical machinery or power lines; it can be on-channel interference from other

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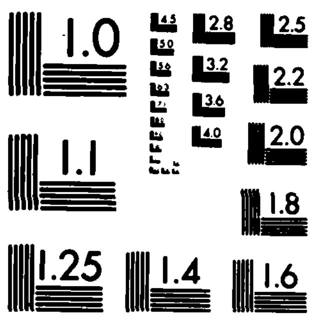

MICROCOPY RESOLUTION TEST CHART

NATIONAL BUREAU OF STANDARDS-1963-A

users; it can be spurious interference resulting from poor receiver design; it can be atmospheric or galactic noise or it can be receiver generated interference. Whatever the source, if it is too great relative to the received signal, the result is a garbled voice data message. The signal-to-noise ratio is of course determined not only by the noise level but also by transmitted power level and by ionospheric absorption.

A properly designed data system can continue to function (perhaps with reduced data rates) under signal-to-noise conditions which would make voice impossible.

Flat Fading

Flat fading is fading of a whole band of frequencies due to time variations in absorption or other causes. Fades can be shallow or deep. They can be compensated for in system design by use of sufficiently high power to maintain adequate signal-to-noise ratio even at the trough of the fade. This, of course, is not always a satisfactory solution since it may require excessive levels of power. Another approach to the problem is by the use of time diversity by the use of message repeats or by interleaving.

Multipath Effects

Consider the occurrence of signals reflected from two separate layers as a result of a single transmission. Let them have equal strength and let them be exactly out of phase with each other. At the receiver, the earliest arriving signal produces a response until the out-of-phase signal appears perhaps a millisecond or two later. The receiver response then returns to zero because of signal cancellation and remains there until the end of the transmission. When the first arriving signal ends, the second arriving signal produces a short response until it too ends. Alternatively, if the two signals are in phase, then the first and last parts of the received signal are of amplitude "one" while the overlapping part of the signal is of amplitude "two" because of signaladdition. Note that this effect is frequency dependent. Since, as the frequency increases, the signals penetrate to increasing depth into the layers, the differential delay between the received signals also changes and therefore the phase relationships change. The result is what one might call selective filtering. One or more relatively narrow bandwidth notches may be cut out of the spectrum of the received signal because of this phenomenon.

Such narrow bandwidth filtering does not have a disastrous effect on SSB voice since voice is very tolerant to notching out parts of the audio spectrum. It has a more severe effect on DSB since the demodulation process for double sideband relies on like characteristics for the two sidebands. It can have a devastating effect on a narrow band data signal located in a null and would have an enhancing effect on a narrow band signal located at a peak.

The mechanism described above assumes a completely stationary ionosphere. Such is not usually the case. Therefore, instead of a stationary pattern of filtering as described, we normally have a slowly varying pattern such that the received signal strength on a particular frequency is time variable. This phenomenon is called selective fading.

Selective Fading

Selective fading produces its most serious effect on narrow band data signals since they may fade in and out with consequent variations in error rate. A way to minimize the effect of selective fading is to provide for in-band frequency diversity whereby the information is transmitted in more than one subchannel of the total available bandwidth to improve the likelihood of satisfactory reception of one of them.

Selective fading can occur only for multi-mode propagation since it depends for its existence upon the existence of more than one signal. The depth of fading will depend upon the relative signal strengths of the modes.

Polarization Fading

This is fading due to the addition and cancellation effects of two particular propagation modes, viz., the ordinary and extraordinary waves. The fading rate tends to be higher than for the other types of fading already mentioned, and can be as fast as several fades per second in some cases. Its effect can be minimized through use of polarization diversity reception which implies the use of two antennas.

Intersymbol Interference

If the elements of a data signal are relatively short, and if multipath exists, signals arriving from the second mode of propagation can appear in the time slot for arrival of the next data bit via the first mode of propagation. The bits interact with each other and it can become impossible to determine what has been transmitted. A way around this problem is to transmit relatively short data bits and leave a guard time before transmission of the next bit.

Miscellaneous Effects

Excessive Interference at Night Because of Reduced Absorption

This factor is particularly observable at the low frequencies since those are the frequencies exhibiting highest level absorption during daylight hours.

Sporadic and Unpredicted Availability of "Abnormal" Frequencies

This is usually associated with the occurrence of Aurora.

Rapid Changes in Propagation Conditions at Sunset and Sunrise

As noted earlier, this results from the change in ionization coincident with the changes in sunlight at the point of reflection.

Sometimes relatively rapid variation in usable frequencies occurs at times other than sunset and sunrise.

Means of Dealing With the Problems

Some means of dealing with the problems have already been introduced. In this section, those already introduced will be collected and others will be added.

Adequate Spectrum Availability

It is useful to have at one's disposal a sufficient number of alternate frequencies adequately distributed across the HF spectrum to maximize the probability of finding a "good" one for all expected propagation conditions. This is a serious problem related to the regulatory situation and to the question of congestion.

Knowledge of the Current Situation

It is useful to know what conditions exist on the assigned frequencies.

- What are the propagation conditions?
- What are the interference conditions?

Frequency Management

It would be useful to have the ability to choose frequencies that produced the least problems.

Adaptive Frequency Selection

Such a system would be useful, and even necessary, for optimum performance.

Alternate Routing

This is an essential feature in order to minimize the effects of blackout and congestion. The success of alternate routing is highly dependent upon the connectivity of the stations within the network.

Antenna Design

Good antenna design is an essential feature of any communication system. The objective of course is to ensure that the maximum energy is radiated in the proper direction, both horizontal and vertical, to achieve successful communication. The vertical angle is of obvious importance for any given geographical configuration because of the geometry concerned. Compromise is usually necessary particularly for mobile communications since a capability must exist to handle a wide variety of geographical situations.

Antenna system design at the ground terminal can be used to reduce the effects of certain types of fading. Space diversity, involving use of two antennas separated in space by several wavelengths, can reduce the effects of fading because the received signals follow slightly different paths and can exhibit uncorrelated fading characteristics. Polarization diversity reception, involving use of two co-located antennas exhibiting orthogonal polarizations, can be used to reduce the effects of polarization fading.

Signal Design

We are concerned with two basic signal types

- Voice
- Data.

Voice

Single Sideband Suppressed Carrier--provides superior performance with respect to Amplitude Modulation because:

- All the transmitted energy contains information.

- The energy is contained in a 3 KHz bandwidth instead of a 6 KHz bandwidth. This results in less noise for the SSB signal and the availability of twice the number of channels.

- In a multipath environment, the effects of selective fading are less severe.

However, because no reference carrier is transmitted, good frequency stability is required at both transmitter and receiver. Frequency offsets of up to about 50 Hz are acceptable. Beyond 100 Hz, intelligibility falls off rapidly.

Companding--provides a means of increasing the effective signal-to-noise ratio and hence the voice intelligibility at the receiver. One such system that has been successfully used for certain applications is known as Rincompex. The principle of Lincompex is to increase the level of low level voice syllables prior to transmission and to reduce their level after reception. This compression of dynamic range of the transmitted signal and subsequent expansion of the received signal results in the low level syllables being received with approximately the same signal-to-noise ratio as the high level syllables. The receiver expansion is controlled by the transmitter through use of a narrow band FM control signal transmitted along with the compressed voice signal. The control signal occupies the top part of the voice spectrum. Unfortunately, while Lincompex has been successfully used, the narrow band FM control channel requires a high degree of frequency stability and the system has fallen into disfavor particularly for mobile operations. It is also relatively expensive.

More recently work is progressing in Canada on a new compander called Syncompex. It uses the same basic principle as Lincompex but implementation is significantly changed. An all-digital implementation is intended to result in a significant cost reduction. More important, a digital control channel is used so that a high degree of frequency stability is not required. In-band frequency diversity is provided in the control channel to overcome the effects of selective fading. In addition, the availability of control channel signals at specific frequencies permits the implementation of automatic frequency control (AFC).

Data

The manner in which data signals are optimally used depends upon the propagation conditions. Ideally one would like to see single mode propagation, and a good signal-to-noise ratio. That would permit use of conventional single channel FSK or like modulation, or of multi-channel FSK, DPSK, or DQPSK or whatever, without problems of selective fading and with a low error rate. Various such multi-channel systems exist. One such system is Knoplex which can achieve 2400

bits per second in a single mode propagation environment using 16 differential quadrature phase shift keyed sub-channels. Several other such multi-channel systems have been experimented with or fully developed. When multipath exists the throughput of a multi-channel system must in general be reduced significantly below the design data rate in order to accommodate the effects of selective fading on the various subchannels.

One disadvantage in using a parallel channel system is that the power assigned to each channel must be less than 1/N (where N is the number of channels) of the available transmitter peak power in order to avoid transmitter saturation. In general, transmitters are both peak power and peak voltage limited. Since power is proportional to voltage squared, occasional voltage saturation can be avoided only if the power in each tone is limited to 1/N2. Such severe limitation is not used in practice. Nevertheless the power ascigned to each sub-channel is less than 1/N. Wider bandwidth (higher data rate) serial transmission would not have this limitation. However, such a modulation would not be usable for the general case where multipath exists because of the effects of inter-symbol interference.

A second problem with multi-tone systems is the unequal distribution of noise or interference across the multi-channels. A result of this unequal distribution can be high error rates on one or more channels concurrent with low error rates on the other channels.

In a multipath environment, one can expect selective fading to affect narrow band data channels and to cause errors unless the power margin is adequate to overcome the effects of the reduced signal-to-noise ratio existing during the fades. One way around this problem is to transmit only short pulses for each band interval and to leave a quard-time after each transmitted pulse to accommodate all multipath. Such a procedure would increase the transmitter and receiver bandwith requirements. This procedure is not generally used.

The more general approach used to overcome the effects of errors due to selective fading and other effects, involves either error detection and correction or ARQ procedures. Both procedures can be effective but both lower the effective data rate. It is to be noted that repeated transmissions in an ARQ system can be used in different ways depending upon the manner in which the system is implemented. The most powerful procedure would be to retain all information thought to be in error for comparison with successive repeats in order to establish a majority rule decision.

departures occur during disturbed conditions and the predictions are therefore of little value during such periods. Furthermore, while predictions can take account of atmospheric and galactic noise, they do not account for man-made interference or on-channel interference generated by other users.

Propagation Predictions

While frequency predictions of the type already discussed do not accommodate abnormal conditions, there are other prediction services which provide short term advice regarding disturbances. These predictions are based upon observation of sunspot and geomagnetic activity. They can provide a warning of expected blackout conditions or enhanced propagation conditions but detailed data on the instantaneous conditions are not generally available, and this kind of prediction cannot be relied on.

Ionospheric Sounding

Ionospheric sounding is a process by which signals are transmitted on all frequencies of interest and received in an associated receiver with a view to determining the characteristics of the propagation medium.

The most general situation involves a special stepped frequency transmitter which emits short pulses on each frequency in turn, a synchronous stepped-frequency receiver which receives those pulses, an analysis unit which categorizes the received signals in terms of amplitude, multipath, doppler and phase characteristics, and a display unit which potrays the received signals in terms of responses from the various ionospheric layers in the form of an ionogram. The sounding system may be vertically oriented wherein transmitter and receiver are located at different places. Vertical sounding is usually considered to be a scientific tool used to determine ionospheric structure at specified locations. Oblique sounding can be used for the same purpose but can also be used to determine ionospheric characteristics relevant to a particular path with the assumption that those characteristics are generally valid over a reasonable area. That system was the Common User Radio Transmission System (CURTS) developed for the U.S. Defense Communications Agency by SRI and manufactured by E.M.I. Cussor of Dartmouth, Nova Scotia.

A second type of generalized system is a swept CW system wherein a swept frequency signal is transmitted and received in a swept frequency receiver. This type of sounder is known as a Chirp Sounder. A commercial variant of this type of sounder is manufactured by B. R. Associates in the U.S.A.

The types of systems noted above are generally used to determine ionospheric characteristics over the entire HF frequency band. A second class of system is one that sounds only on the frequencies assigned to the particular service. One such system is the CHEC (Channel Evaluation and Calling) system developed in Canada in the early 1970's. That system was designed to evaluate the quality of transmission for aircraft channels through use of stepped CW signals on each assigned frequency. Additionally, the current level of interference was measured at the ground terminal and communicated to participating aircraft through special coding applied to the channel evaluation signal.

The CHEC system is one particular type of channel evaluation system. It is an off-line system in that it is physically separate from the communication system. Information provided by it is interpreted by an operator and used by him to select the appropriate frequency. An advance on this type of system would be one wherein the channel evaluation equipment automatically selected the appropriate frequency, thereby eliminating the operator function.

A more comprehensive type of channel evaluation system is one wherein the channel evaluation equipment is largely indistinguishable from the associated communications equipment. One such equipment developed by E.M.I. Cussor of Dartmouth, Nova Scotia was known as the MUFFIN system. In that system, the complement of frequencies was regularly evaluated by the same equipment that performed the communication function. Communications in progress were interrupted periodically to check the continuing validity of choice.

Another system of this type is now in development at the Communications Research Center in Canada. It involves channel evaluation for low density radio telephone communications to remote communities in Northern Canada.

An important distinction between channel evaluation systems involves the characteristics of the channel evaluation techniques. The technique can use, at one end of the scale, a detailed impulse response of the ionosphere on each channel of interest coupled with a detailed measurement of channel interference characteristics, and at the other end of the scale, a real-time performance evaluation on each frequency using a test communication signal. A third alternative can be that of determining nothing more than those frequencies on which propagation is possible without regard to detailed characteristics or detailed communication performance. The technique used determines the complexity of implementation and should be determined by the specific application.

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